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by Lloyd S. Jernell

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SUMMARY

An investigation has been conducted in the Langley Unitary Plan wind tunnel to determine the effects on the aerodynamic characteristics in pitch and sideslip of a series of wing planform modifications to a wing-body-tail model. The tests were conducted at angles of attack from about -3° to 25° for angles of sideslip of about 0° and 5° , at Mach numbers from 1.70 to 4.63, and a Reynolds number per foot (per 0.3048 m) of 3.0×10^6 .

The addition of trailing-edge inserts to the basic wing progressively reduced the pitch-up characteristics occurring at the lower Mach numbers.

Increasing the wing area lessened the adverse effects on directional stability which occurred with increasing lift coefficient. The wing planform did not affect the effective dihedral except to improve the linearity with respect to lift as the aspect ratio was decreased. In all cases the addition of wing area was accompanied by an increase in the maximum lift-drag ratio.

INTRODUCTION

Much research is currently being devoted to the study of the stability and performance characteristics of aircraft configurations for Mach numbers up to and greater than 4. Reference 1 presents the results of a study of the effects of wing planform on the longitudinal and lateral characteristics of a wing-body-tail configuration for angles of attack up to about 26° at Mach numbers from 1.57 to 2.87. The purpose of this paper is to present the results of an investigation of the effects of additional planform modification for Mach numbers from 1.70 to 4.63. The basic configuration, an ogive-cylinder body with a 61.69° swept wing, is the same as the basic model of reference 1 with the exception of a 4-inch extension to the aft section of the fuselage. Planform modifications include (1) a full-span leading-edge extension providing a sweep angle of 67.01° , (2) four

full-span trailing-edge inserts which progressively vary the planform from that of a swept wing to that of a clipped-tip diamond, (3) a half-span trailing-edge insert, and (4) a cranked-tip swept wing. The tests were conducted in the Langley Unitary Plan wind tunnel at angles of attack from about -3° to 25° for angles of sideslip of 0° and 5° . The Reynolds number per foot (per 0.3048 m) was 3.0×10^6 .

SYMBOLS

The longitudinal and lateral data are presented about the stability- and body-axes systems, respectively. The units used for the physical quantities in this paper are given both in the U.S. Customary Units and in the International System of Units (SI). Factors relating the two systems are given in reference 2 and those used in the present investigation are given in the following table:

Physical quantities	U.S. Customary Unit	Conversion factor (*)	SI unit
Area	sq ft	0.0929	sq meter (sq m)
Length	in.	0.0254	meter (m)
	ft	0.3048	meter (m)
Temperature	$^\circ\text{F} + 459.67$	5/9	degrees Kelvin ($^\circ\text{K}$)

*Multiply value given in U.S. Customary Unit by conversion factor to obtain equivalent value in SI unit.

- b wing span, 1.667 ft (0.508 m)
- \bar{c} mean geometric chord of respective wings, ft (m)
- \bar{c}_b mean geometric chord of basic wing, 0.451 ft (0.137 m)
- C_D drag coefficient based on respective wing areas, $\frac{\text{Drag}}{qS}$
- C_L lift coefficient based on respective wing areas, $\frac{\text{Lift}}{qS}$
- C_l rolling-moment coefficient based on respective wing areas, $\frac{\text{Rolling moment}}{qSb}$
- $C_{l,b}$ rolling-moment coefficient based on basic wing area, $\frac{\text{Rolling moment}}{qS_b b}$
- C_{l_β} effective dihedral parameter based on respective wing areas, $\frac{\Delta C_l}{\Delta \beta}$

$C_{l_{\beta,b}}$	effective dihedral parameter based on basic wing area, $\frac{\Delta C_{l,b}}{\Delta \beta}$
C_m	pitching-moment coefficient based on respective wing areas, $\frac{\text{Pitching moment}}{qS\bar{c}_b}$
$C_{m,b}$	pitching-moment coefficient based on basic wing area, $\frac{\text{Pitching moment}}{qS_b\bar{c}_b}$
C_n	yawing-moment coefficient based on respective wing areas, $\frac{\text{Yawing moment}}{qSb}$
$C_{n,b}$	yawing-moment coefficient based on basic wing area, $\frac{\text{Yawing moment}}{qS_b b}$
$C_{n\beta}$	directional-stability parameter based on respective wing areas, $\frac{\Delta C_n}{\Delta \beta}$
$C_{n\beta,b}$	directional-stability parameter based on basic wing area, $\frac{\Delta C_{n,b}}{\Delta \beta}$
C_Y	side-force coefficient based on respective wing areas, $\frac{\text{Side force}}{qS}$
$C_{Y,b}$	side-force coefficient based on basic wing area, $\frac{\text{Side force}}{qS_b}$
$C_{Y\beta}$	side-force parameter based on respective wing areas, $\frac{\Delta C_Y}{\Delta \beta}$
$C_{Y\beta,b}$	side-force parameter based on basic wing area, $\frac{\Delta C_{Y,b}}{\Delta \beta}$
L/D	lift-drag ratio
M	free-stream Mach number
q	free-stream dynamic pressure, lb/sq ft (N/sq m)
r	radius, in. (cm)
S	area of respective wings, sq ft (sq m)
S_b	basic wing area, 0.694 sq ft (0.0645 sq m)
α	angle of attack, referenced to fuselage center line, deg
β	angle of sideslip, referenced to fuselage center line, deg

Wing Identification

A two-group numbering system is used to identify the various configurations. The first group of numbers refers to the leading-edge extension and gives in percent the amount of extension of the basic-wing root chord. The associated subscript gives the spanwise extent of the leading-edge modification as a percent of the semispan. The second group refers to the trailing-edge insert and expresses in percent the basic root-chord extension: the subscript gives the spanwise extent as a percent of the semispan. A group number of zero refers to the leading edge or trailing edge of the basic wing. Thus, for example, for configuration 67₁₀₀-200₅₀, the wing leading edge has been extended forward at the root 67 percent of the basic root chord with the extension tapering to zero at 100 percent $b/2$ and the trailing edge has been extended aft at the root 200 percent of the basic root chord with the insert tapering to zero at 50 percent $b/2$.

APPARATUS AND METHODS

Model

Details of the model are presented in figure 1. The configuration was the midwing type having an ogive-cylinder fuselage. The vertical tail consisted of a constant-thickness slab with a wedge-shaped leading edge and a trapezoidal planform.

The wing was composed of a main spar to which leading- and trailing-edge extensions could be attached. The basic wing (0-0), shown by the solid lines in figure 1, had an airfoil section consisting of the forward one-third of the NACA 63-006 airfoil which faired into the spar and had a constant thickness from the one-third chord to the trailing edge. The leading edge of the basic wing had a sweep angle of 61.69° . The full-span leading-edge extension provided an increase in the basic-wing center-line chord of 67 percent, no extension of the tip, and an increase of the sweep angle to 67.01° . The airfoil section for the extended leading-edge configuration differed from that of the basic wing only in the lengthening of the constant-thickness aft section. Four full-span trailing-edge inserts provided increases in the basic-wing center-line chord of 67 percent, 133 percent, 200 percent, and 280 percent and varied the wing planform from a swept wing to a clipped-tip diamond. A semispan trailing-edge insert provided an increase in the wing center-line chord of 200 percent. Also included was a cranked wing which was obtained by cranking forward the outboard 30 percent of the basic wing to provide a leading-edge sweep angle of the outboard section of 35.08° .

Tunnel

The investigation was conducted in both the low and high Mach number test sections of the Langley Unitary Plan wind tunnel, which is a variable-pressure return-flow tunnel.

The test sections are 4 feet (121.92 cm) square and approximately 7 feet (213.36 cm) long. The nozzles leading to the test sections are of the asymmetric sliding-block type and permit a continuous variation of Mach number from about 1.5 to 2.9 in the low Mach number test section and from 2.3 to 4.7 in the high Mach number test section.

Measurements, Corrections, and Tests

Aerodynamic forces and moments were measured by means of a sting-supported six-component electric strain-gage balance mounted within the fuselage. The base pressure was measured by means of static-pressure orifices located at the base of the fuselage and within the balance cavity. Boundary-layer transition strips approximately 1/16 inch (0.159 cm) wide were located 0.7 inch (1.778 cm) aft of the leading edges of the tail and wing, measured in the streamwise direction, and 0.7 inch (1.778 cm) aft of the nose apex. These strips were composed of No. 60 carborundum grains embedded in a plastic adhesive.

The tests were conducted at Mach numbers of 1.70, 2.16, 2.87, 3.96, and 4.63. The Reynolds number per foot (per 0.3048 m) was 3.0×10^6 . The angle-of-attack range was from about -3° to 25° for angles of sideslip of 0° and 5°. Angles of attack and sideslip have been corrected for tunnel flow misalignment and model-support system deflection under aerodynamic loading. The drag coefficients were adjusted to a condition of free-stream static pressure at the base of the fuselage. The stagnation dewpoint was maintained low enough to assure negligible condensation effects (-30° F) (238.7° K).

PRESENTATION OF RESULTS

The longitudinal data are based on the mean geometric chord of the basic wing and the areas of the respective wings, and are referenced to the respective quarter chord. (See table in fig. 1.) Also presented are the pitching-moment coefficients based on the basic-wing area and a reference moment center yielding a 1-inch static margin. The lateral data are computed for both basic and respective wing areas and are referenced to the balance moment center. (See fig. 1.) The data are presented as follows:

	Figure
Effect on longitudinal characteristics of -	
Full-span trailing-edge inserts	2
Semispan trailing-edge insert	3
Full-span leading-edge extension	4
Wing crank	5
Pitching-moment characteristics for a static margin of 1 inch	6

	Figure
Variation with α of (data based on respective wing areas) -	
$C_{l_{\beta}}$	7
$C_{n_{\beta}}$	8
$C_{Y_{\beta}}$	9
Variation with α of (data based on basic wing area) -	
$C_{l_{\beta,b}}$	10
$C_{n_{\beta,b}}$	11
$C_{Y_{\beta,b}}$	12

DISCUSSION

Longitudinal Characteristics

The tail-off longitudinal data for the various wings, based on their respective areas and referred to their respective quarter-chord locations (fig. 1), are presented in figures 2 to 5. Because of the differences in reference dimensions, these results are not directly comparable, with the exception of L/D which is independent of the reference areas. The results for the various full-span trailing-edge inserts (fig. 2) indicate substantial increases in maximum L/D throughout the Mach number range as the root chord of the insert is increased. This increase in L/D is primarily a result of the favorable decrease in the ratio of fuselage volume to wing area. A similar effect occurs for the semispan trailing-edge insert (fig. 3) and the full-span leading-edge extension (fig. 4), although in these cases part of the improvement in L/D for the leading-edge extension may be due to a reduction in drag associated with the increase in leading-edge sweep. Because of an increase in minimum drag the cranked wing tip (fig. 5) slightly reduces the maximum value of L/D for Mach numbers up to 2.87. However, at the two highest Mach numbers the cranked tip results in a slightly higher maximum L/D because the minimum drag increase is offset by an improved drag due to lift.

The pitching-moment characteristics for the various wings are compared in figure 6 on the basis of a low-lift static margin of 1 inch and a common reference area (that for wing 0-0). Without the vertical tail the model should be symmetrical with respect to the horizontal plane and, therefore, would exhibit a pitching-moment coefficient of zero at $C_L = 0$. The deviations from zero indicated are believed to be due to a slight model asymmetry. The addition of the full-span trailing-edge inserts (fig. 6(a)) tends progressively to relieve a marked pitch-up characteristic at the two lowest Mach numbers and to provide the more linear variation associated with a decrease in wing aspect ratio. For Mach numbers greater than 2.87, there is essentially no indication of pitch-up for any of the wings as the leading edge becomes supersonic. In fact, for

$M = 3.96$ and 4.63 , the wings begin to indicate a pitch-down characteristic with increasing lift coefficient. A similar result is attained for the semispan trailing-edge insert (fig. 6(b)) – the addition of the insert tends to relieve the pitch-up characteristics at the lower Mach numbers and at the higher Mach numbers a pitch-down tendency occurs for both wings. The addition of a full-span leading-edge extension in conjunction with the 67100 trailing edge (fig. 6(c)) also reduces the wing aspect ratio and tends to lessen pitch-up at $M = 2.16$ but has little or no effect at the higher Mach numbers. The cranked-wing modification (fig. 6(d)) primarily influences the tip-separation effects and results in an increased stability at the higher lift coefficients throughout the Mach number range.

Lateral Characteristics

The lateral derivatives presented herein are incremental values between $\beta = 0^\circ$ and $\beta = 5^\circ$. The differences in the corresponding angles of attack and lift coefficients for the two sideslip positions are within the accuracy of the data. The variations of the sideslip derivatives with angle of attack for the various configurations both with and without the wing and with and without the vertical tail are presented in figures 7 to 9. These results are based on the respective wing areas and the balance moment center and thus are not directly comparable. However, one fact should be noted regarding the effect of the wing on the directional-stability characteristics. At the two lowest Mach numbers (figs. 8(a) and 8(b)), the presence of a wing generally results in an increase in tail effectiveness and a higher level of $C_{n\beta}$ at the higher angles of attack. This increase is believed to be due to the presence of the wing which prevents an adverse effect of body sidewash at the tail. At the higher Mach numbers (figs. 8(c) to 8(e)), however, the presence of the wing generally results in a decrease in directional stability for the complete model. This decrease is associated with the reduction in the dynamic pressure in the vicinity of the tail that might be expected in the flow field above the wing for this Mach number range. However, for a given Mach number the angle of attack at which $C_{n\beta}$ becomes zero varies only slightly with changes in planform.

The variations of the sideslip derivatives with lift coefficient are presented in figures 10 to 12 for the various configurations. (All coefficients are based on the area of the basic wing and referred to the balance moment center.) It should be pointed out that the results at a given value of C_L represent a constant-weight condition, the wing loading varying because of changes in the wing area.

The rolling-moment coefficient results (fig. 10) show little effect of planform other than a general improvement in linearity as the aspect ratio is reduced. At the lowest Mach number an abrupt change in the variation of $C_{l\beta,b}$ with C_L occurs for the basic wing, probably as a result of tip flow separation. This effect is essentially

eliminated through the use of the cranked wing tip. As the Mach number increases, the level of effective dihedral is generally reduced for each wing.

The directional-stability characteristics (fig. 11) indicate less deterioration with increasing C_L as the wing area is increased by the trailing-edge extensions. This apparent improvement results from the fact that the wings with larger areas and hence less loading provide a given lift at a lower angle of attack and delay the detrimental effects of forebody vorticity on the directional stability.

CONCLUSIONS

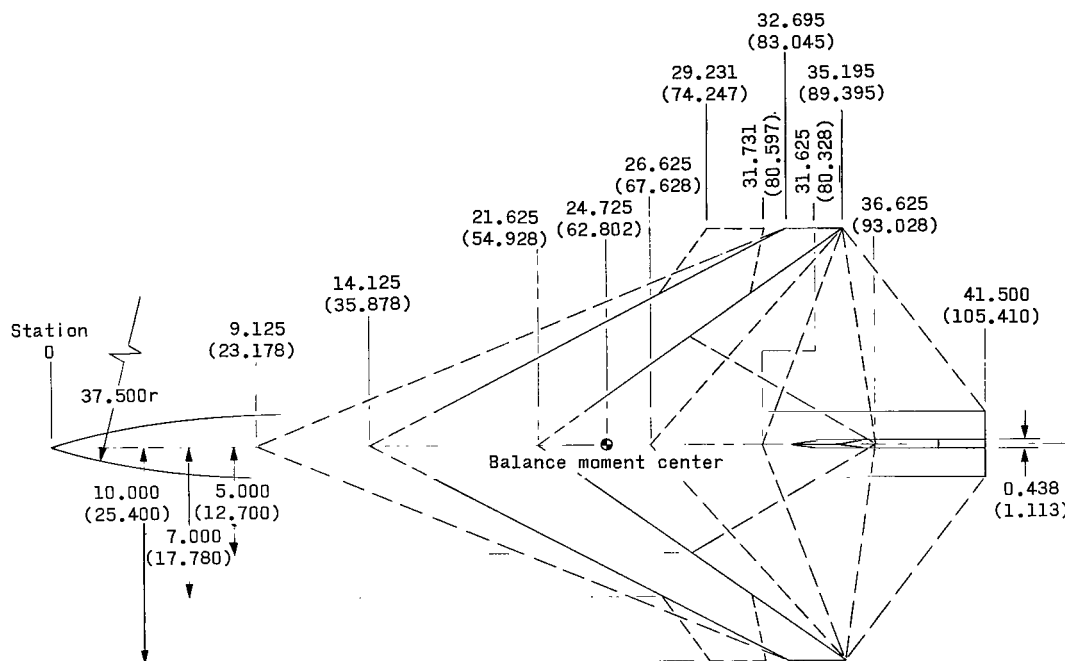
An investigation has been conducted to determine the effects of a series of wing-planform modifications on the aerodynamic characteristics of a wing-body-tail model at Mach numbers from 1.70 to 4.63. The results are summarized as follows:

1. In all cases an increase in wing area was accompanied by an increase in the maximum lift-drag ratio.
2. The addition of the trailing-edge inserts to the basic wing progressively reduced the pitch-up characteristics occurring at the lower Mach numbers.
3. The deterioration of the directional stability with increasing lift coefficient was lessened for the condition of constant weight (or lift) by the addition of wing area.
4. Wing planform did not affect the effective dihedral except to improve the linearity with respect to lift as the aspect ratio was decreased.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 30, 1965.

REFERENCES

1. McKinney, Royce L.; and Jernell, Lloyd S.: Effects of Wing Planform on the Aerodynamic Characteristics of a Wing-Body-Tail Model at Mach Numbers 1.57, 2.16, and 2.87. NASA TM X-1065, 1965.
2. Mechtly, E. A.: The International Systems of Units - Physical Constants and Conversion Factors. NASA SP-7012, 1964.



Leading edge	Trailing edge	Area		\bar{c}		0.25 \bar{c} from nose	
		sq ft	sq m	in.	cm	in.	cm
Basic (0)	Basic (0)	0.694	0.0645	5.417	13.759	23.217	58.971
	67 ₁₀₀	1.042	.0968	8.611	21.872	23.082	58.628
	133 ₁₀₀	1.389	.1290	11.875	30.163	23.795	60.439
	200 ₁₀₀	1.736	.1613	15.167	38.524	24.425	62.040
	280 ₁₀₀	2.152	.1999	19.126	48.580	25.670	65.202
Cranked	200 ₅₀	1.215	.1129	13.095	33.261	22.789	57.884
	Cranked	0.694	.0645	5.417	13.759	22.892	58.146
	67 ₁₀₀	1.389	.1290	11.875	30.163	20.620	52.375

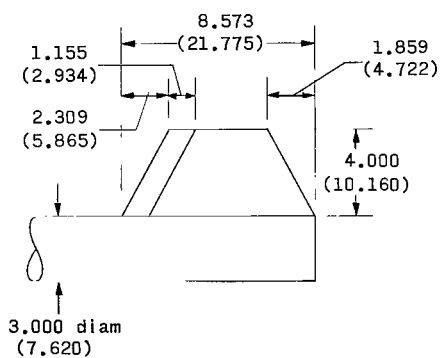
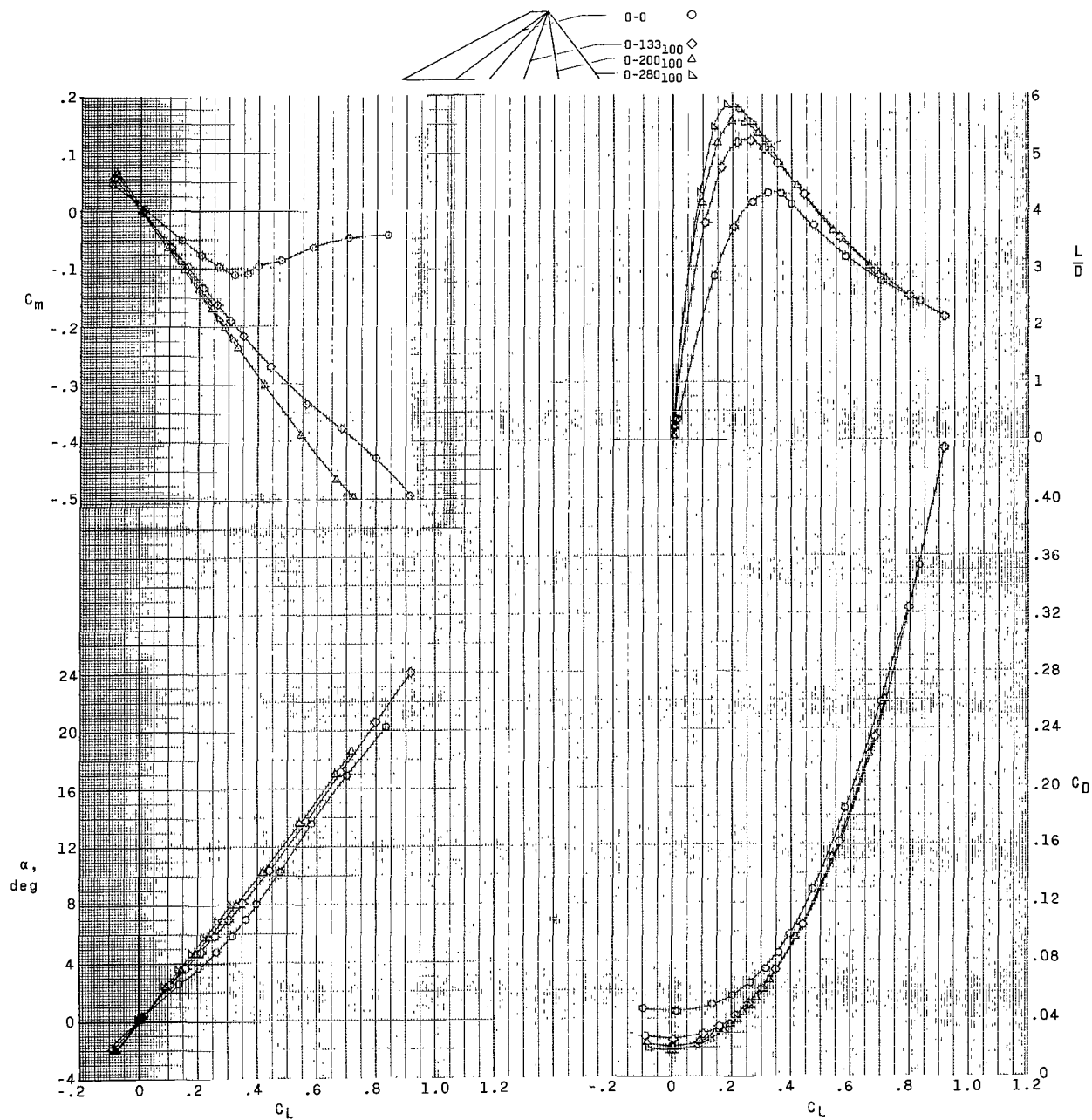
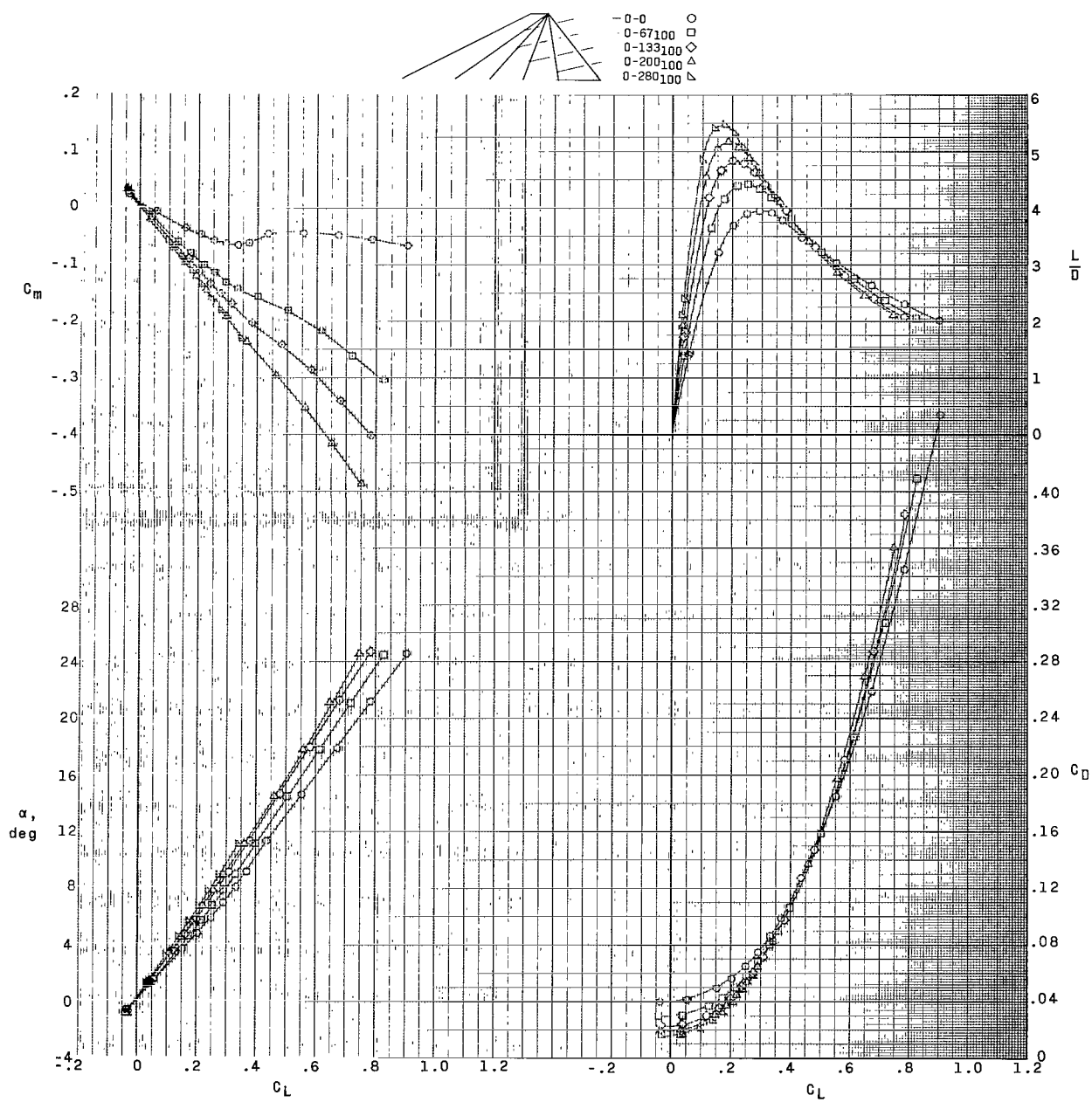


Figure 1.- Model details. Dimensions are given in inches and parenthetically in centimeters unless otherwise noted.



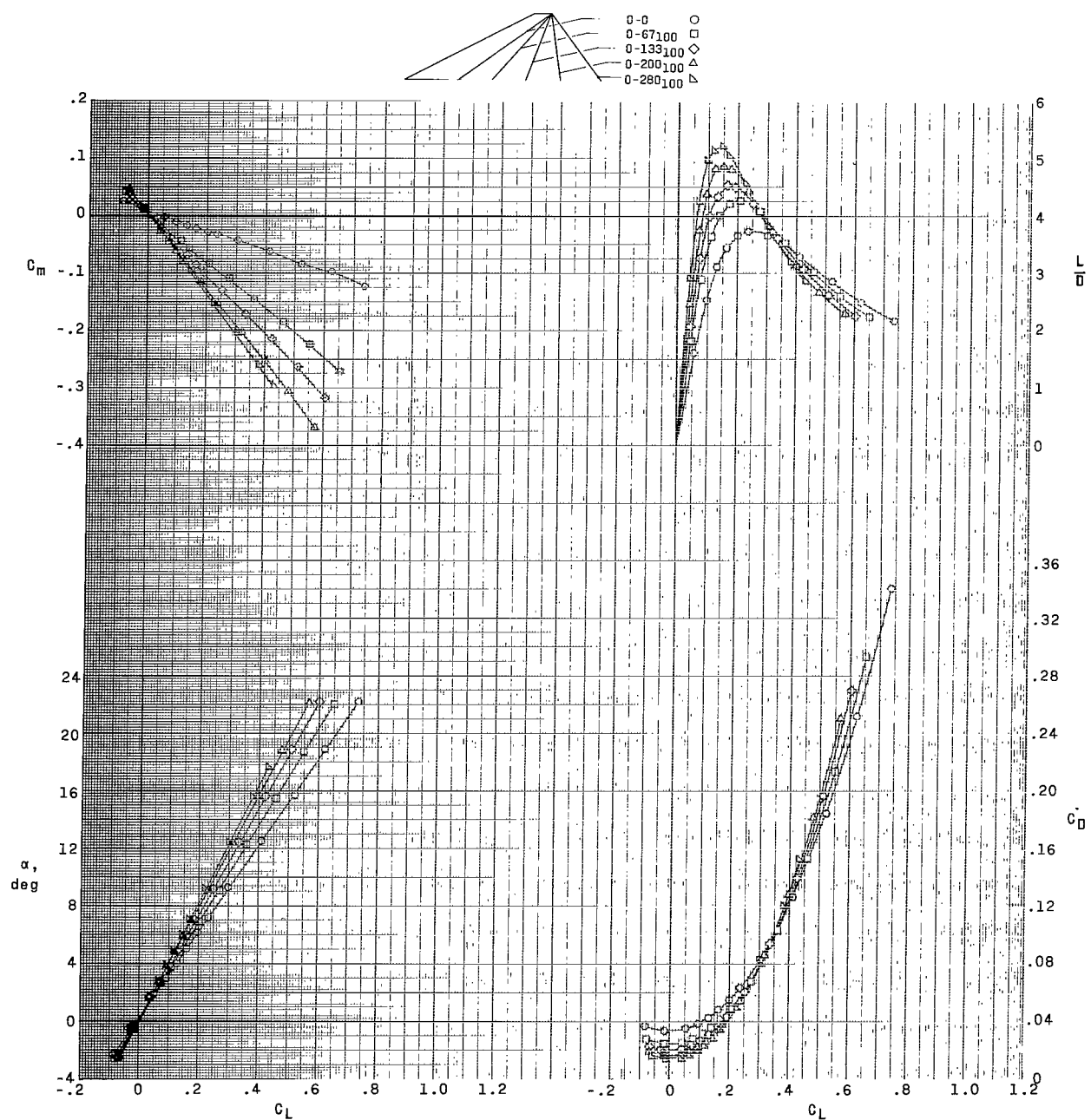
(a) $M = 1.70$.

Figure 2.- Effect of full-span trailing-edge inserts on the longitudinal characteristics. Tail off.
Data based on respective wing areas and referenced to respective $0.25\bar{c}$ locations.



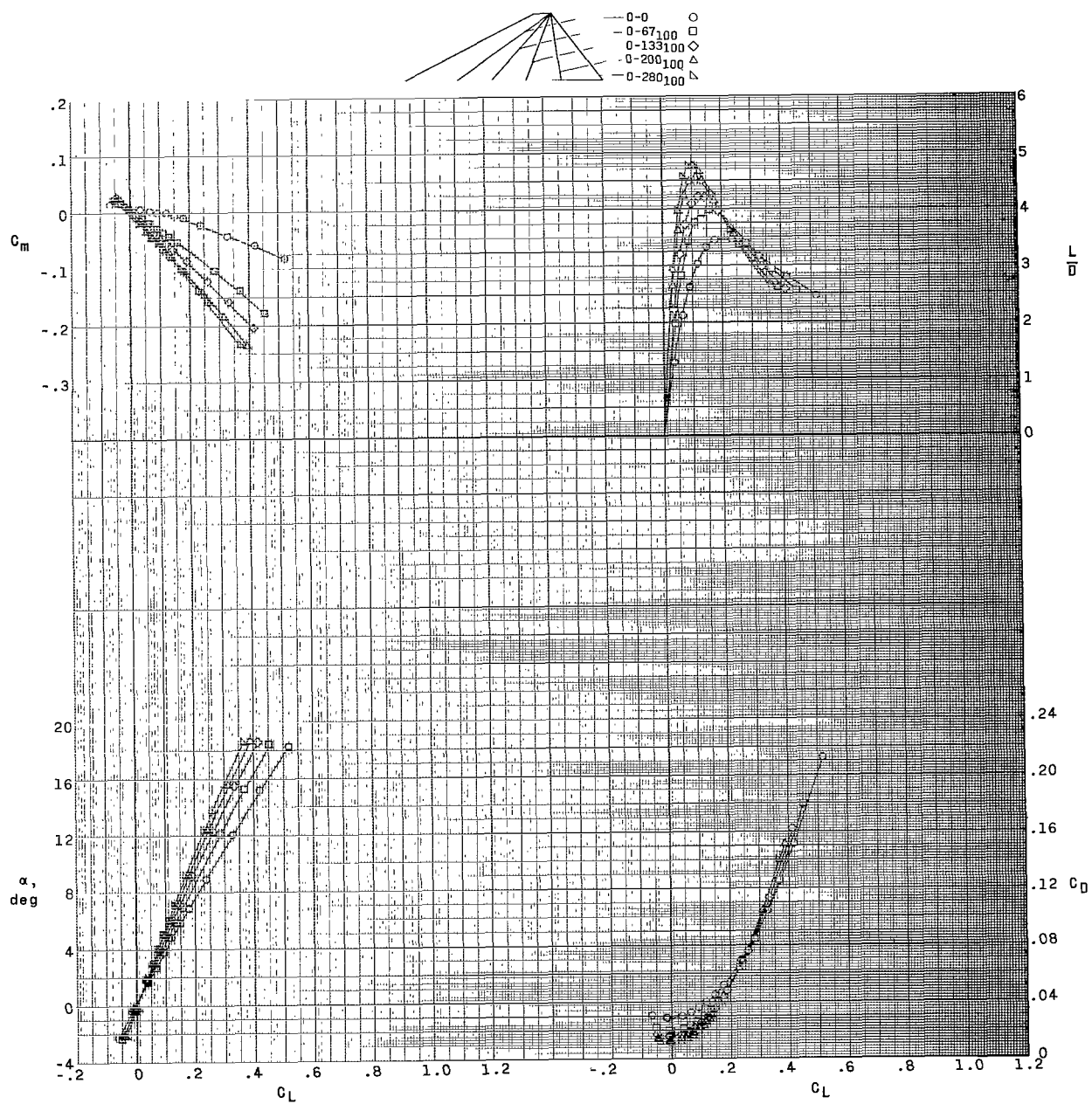
(b) $M = 2.16$.

Figure 2.- Continued.



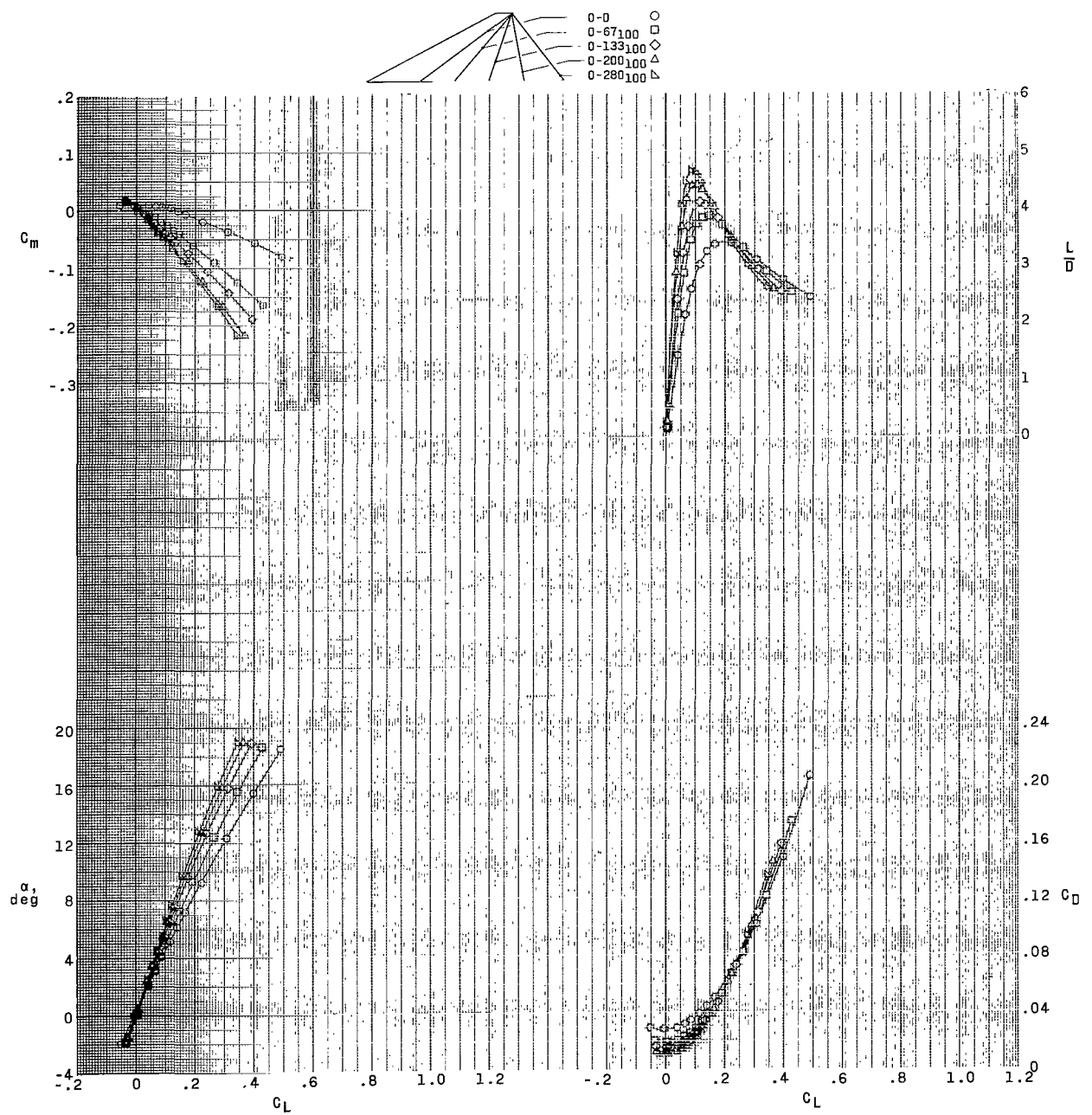
(c) $M = 2.87$.

Figure 2.- Continued.



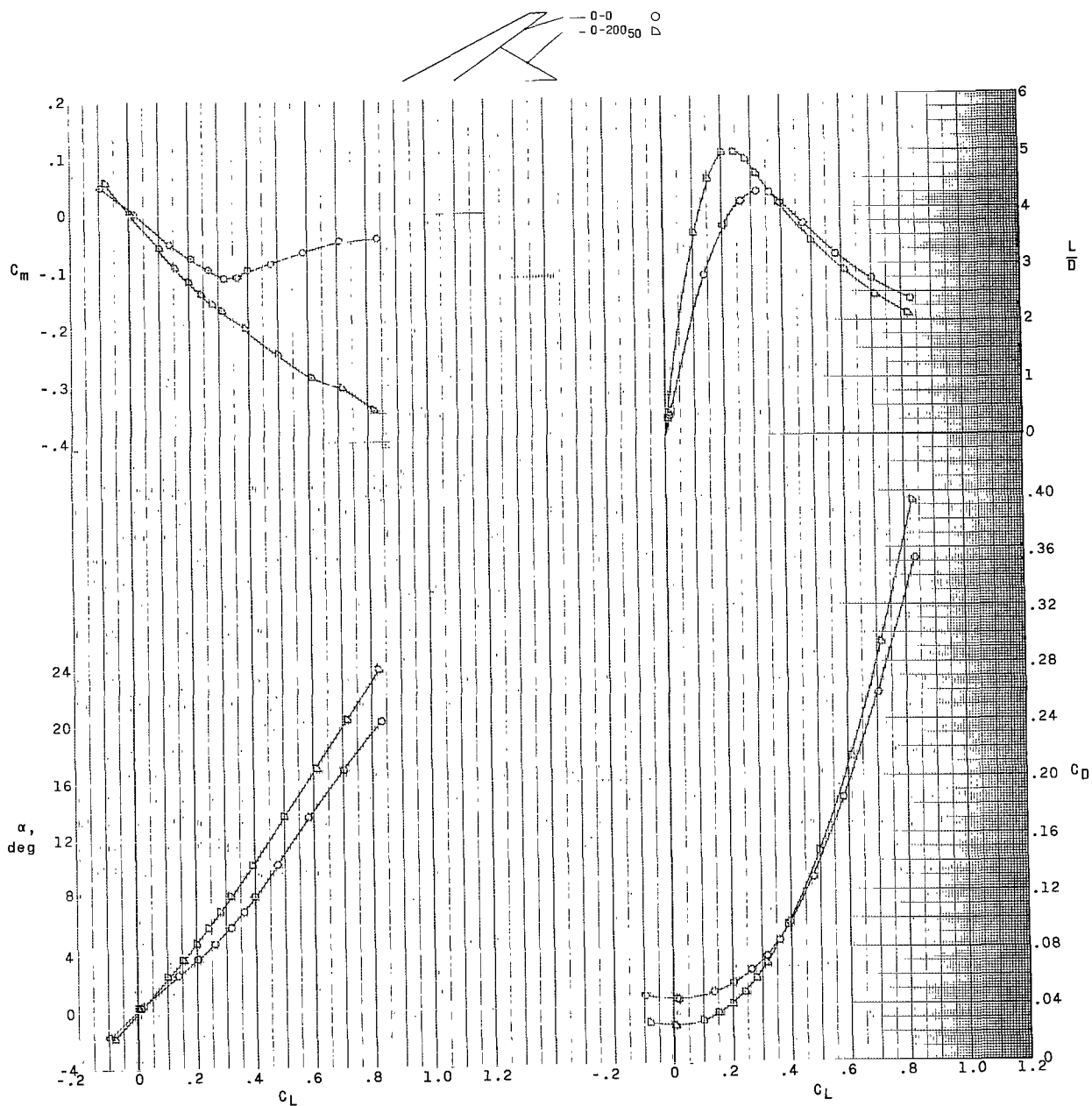
(d) $M = 3.96$.

Figure 2.- Continued.



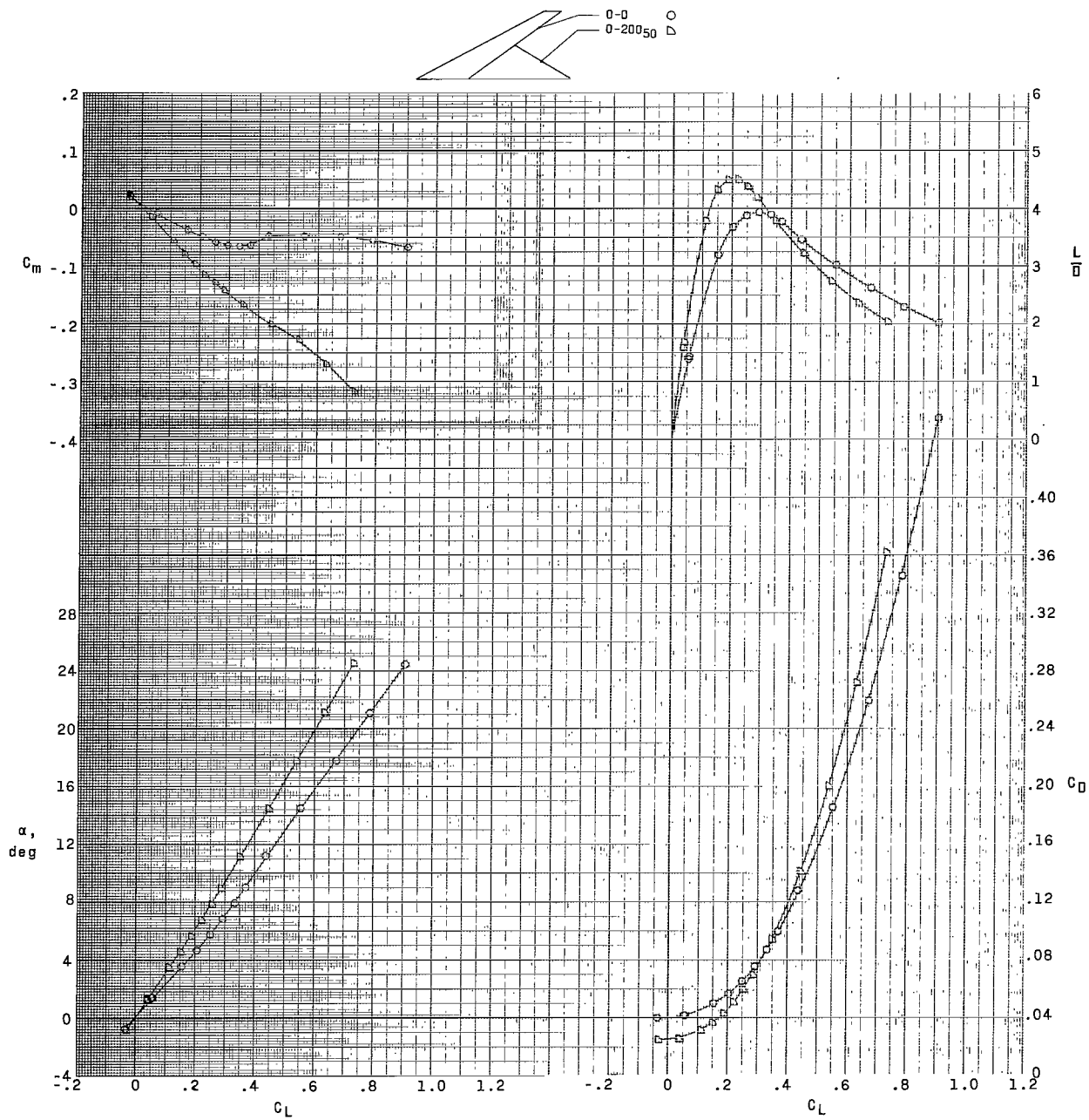
(e) $M = 4.63$.

Figure 2.- Concluded.



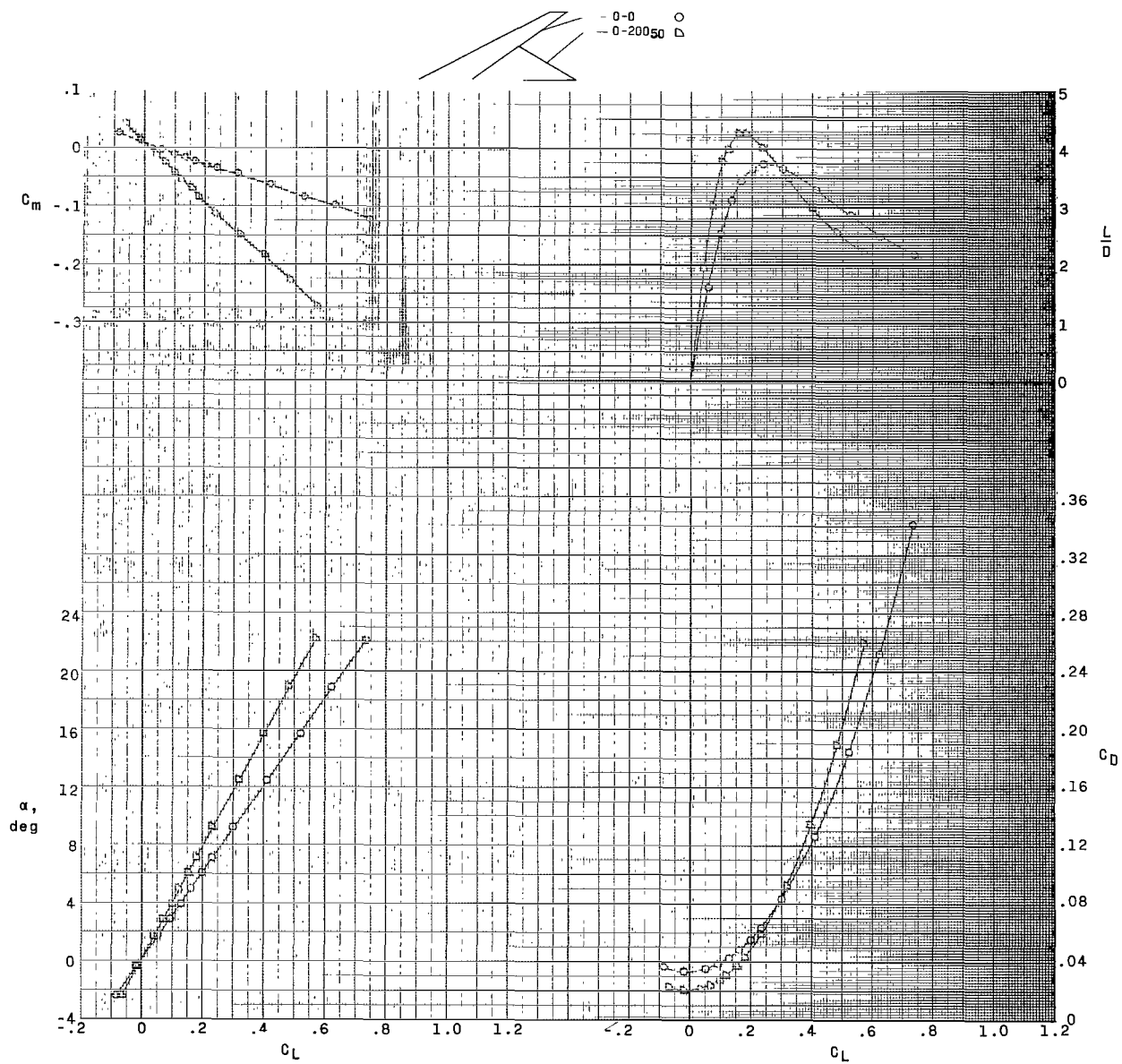
(a) $M = 1.70$.

Figure 3.- Effect of a semispan trailing-edge insert on the longitudinal characteristics. Tail off.
Data based on respective wing areas and referenced to respective $0.25\bar{c}$ locations.



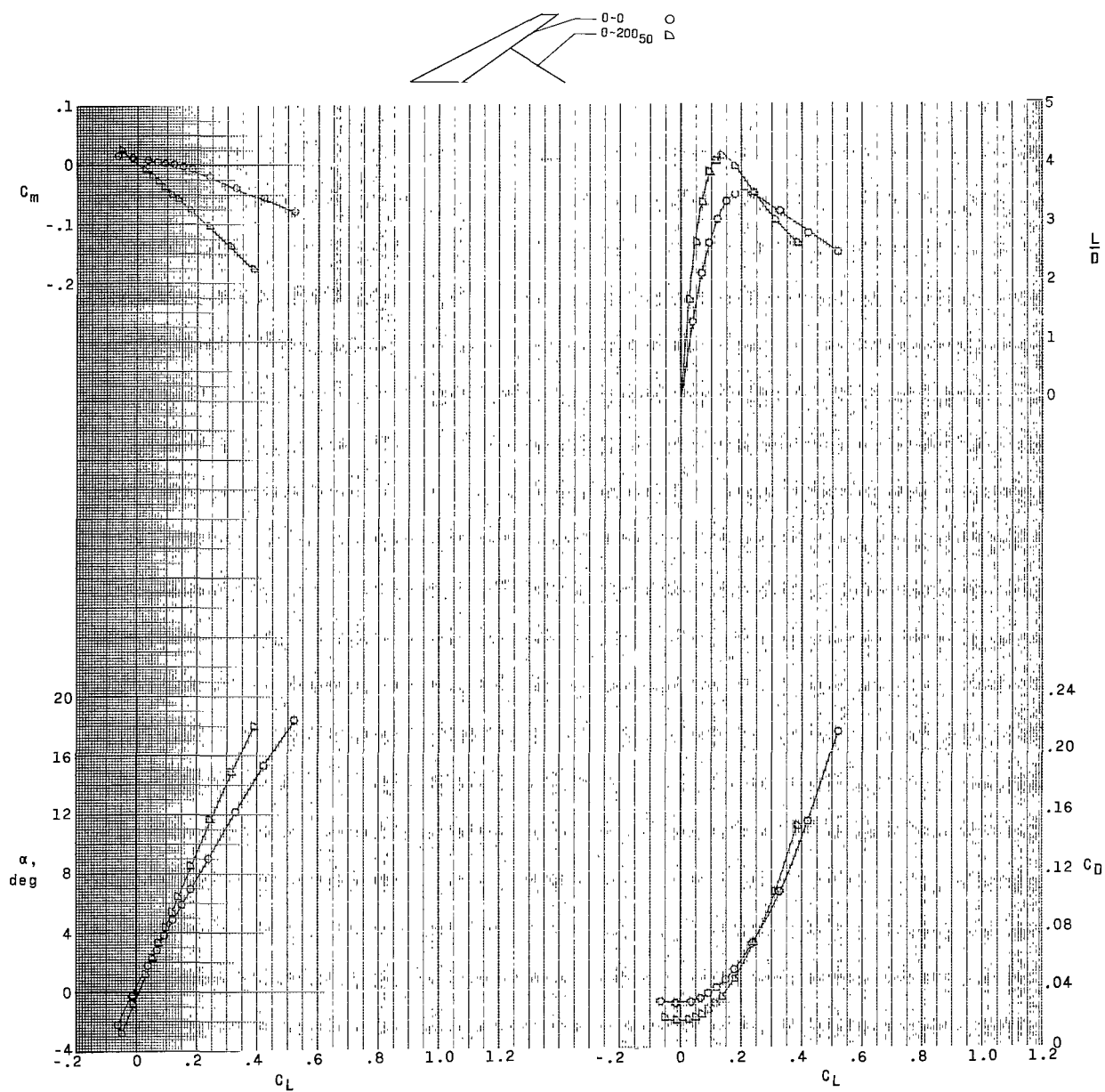
(b) $M = 2.16$.

Figure 3.- Continued.



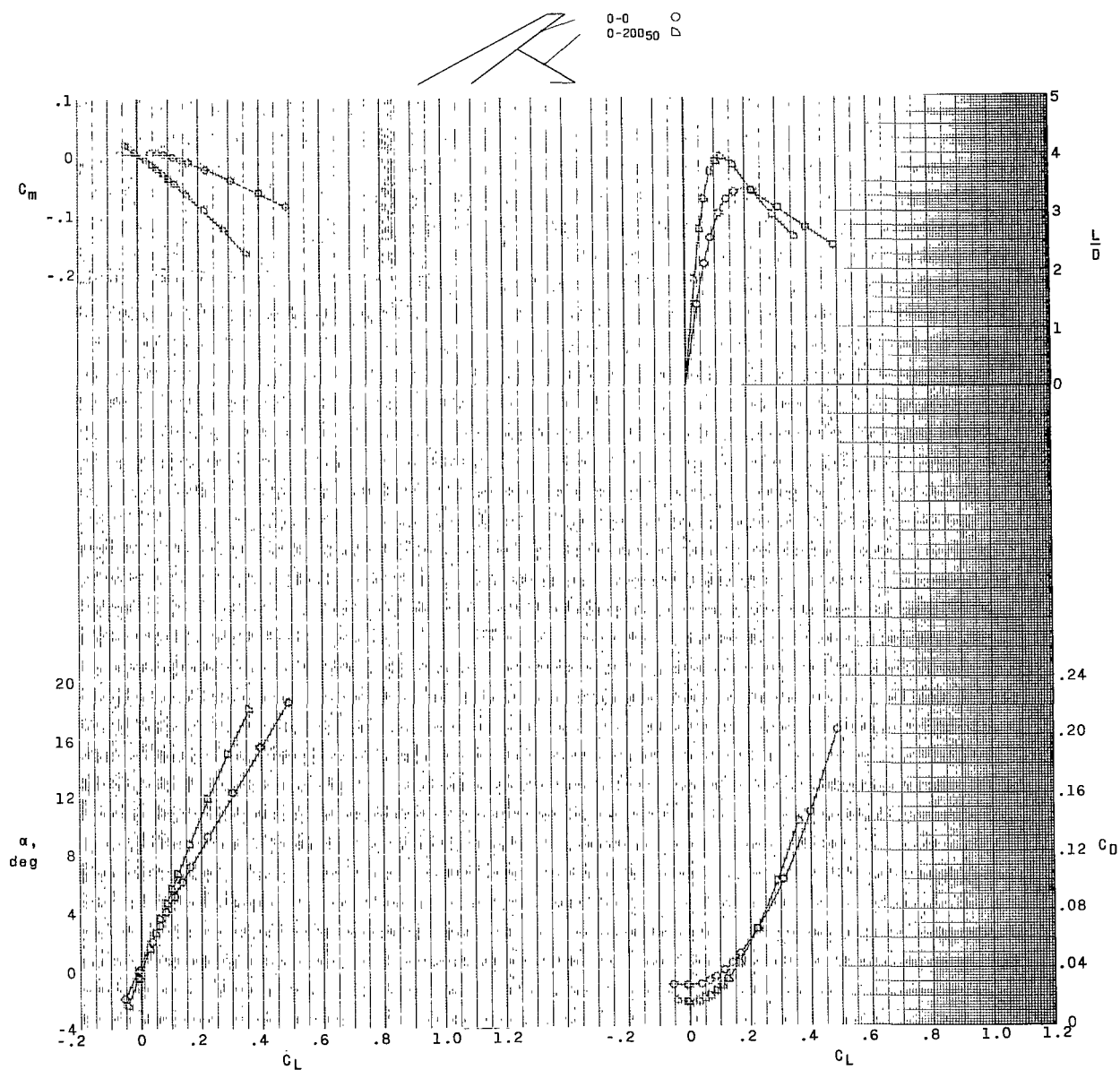
(c) $M = 2.87$.

Figure 3.- Continued.



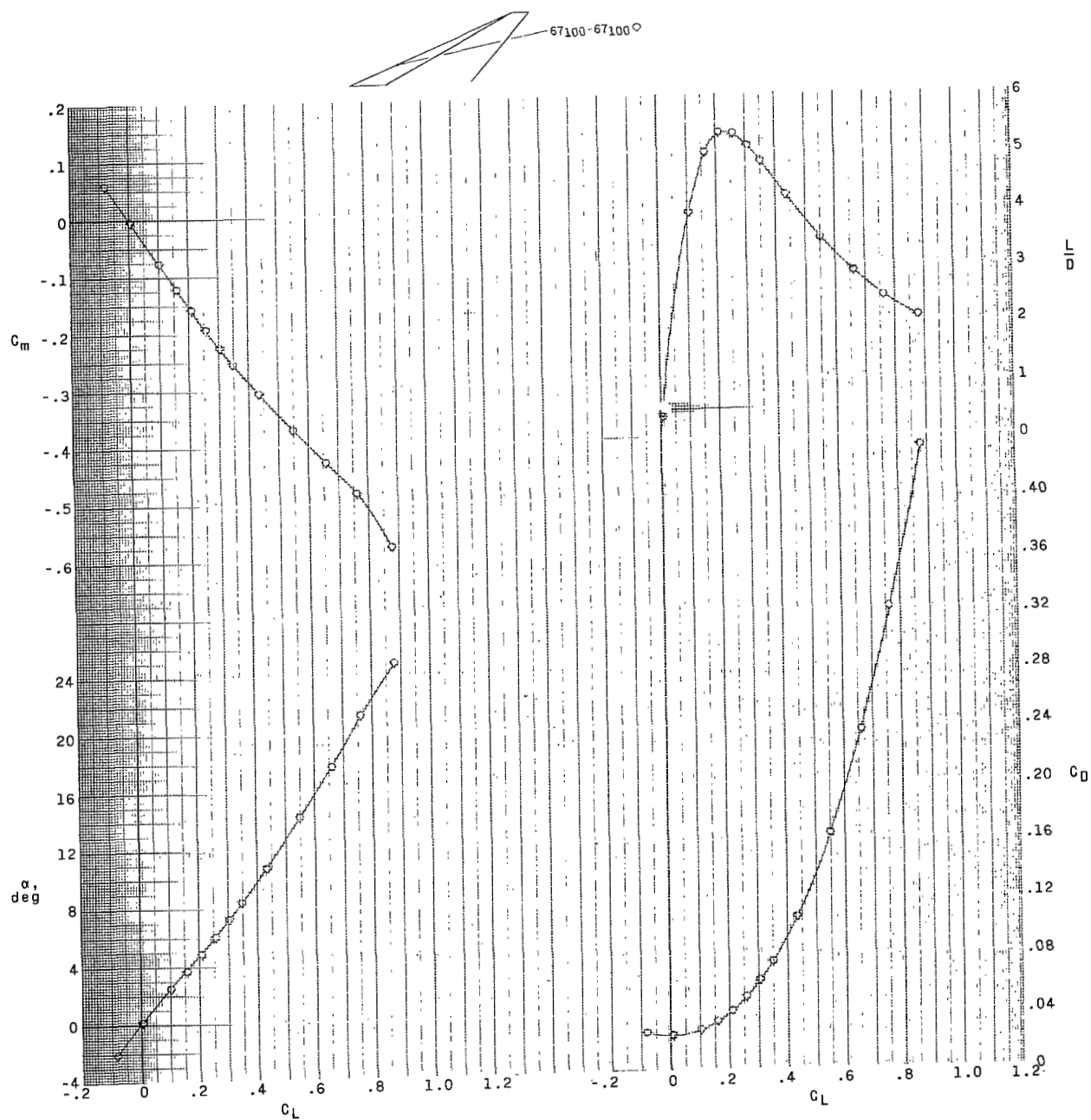
(d) $M = 3.96$.

Figure 3.- Continued.



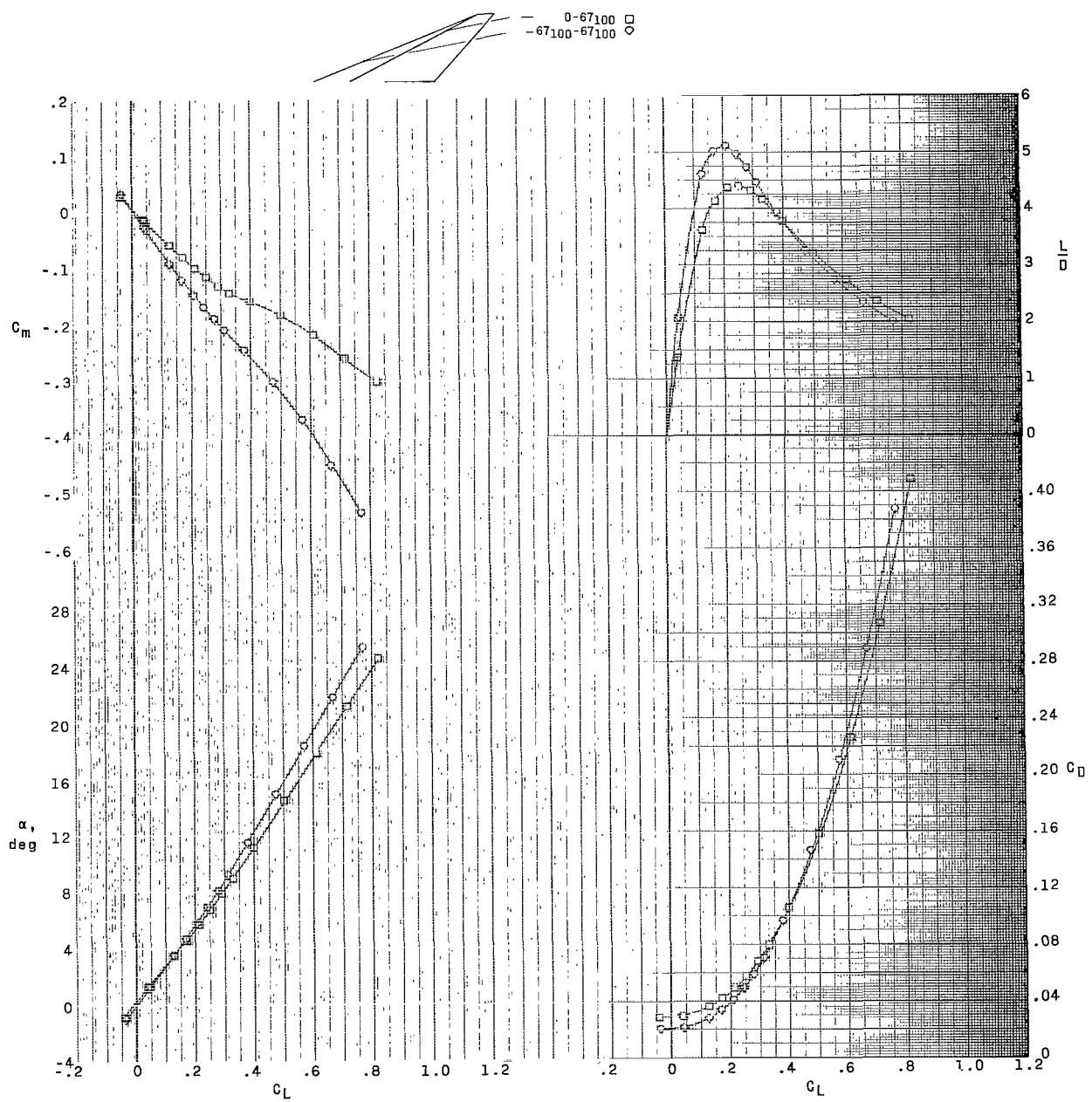
(e) $M = 4.63$.

Figure 3.- Concluded.



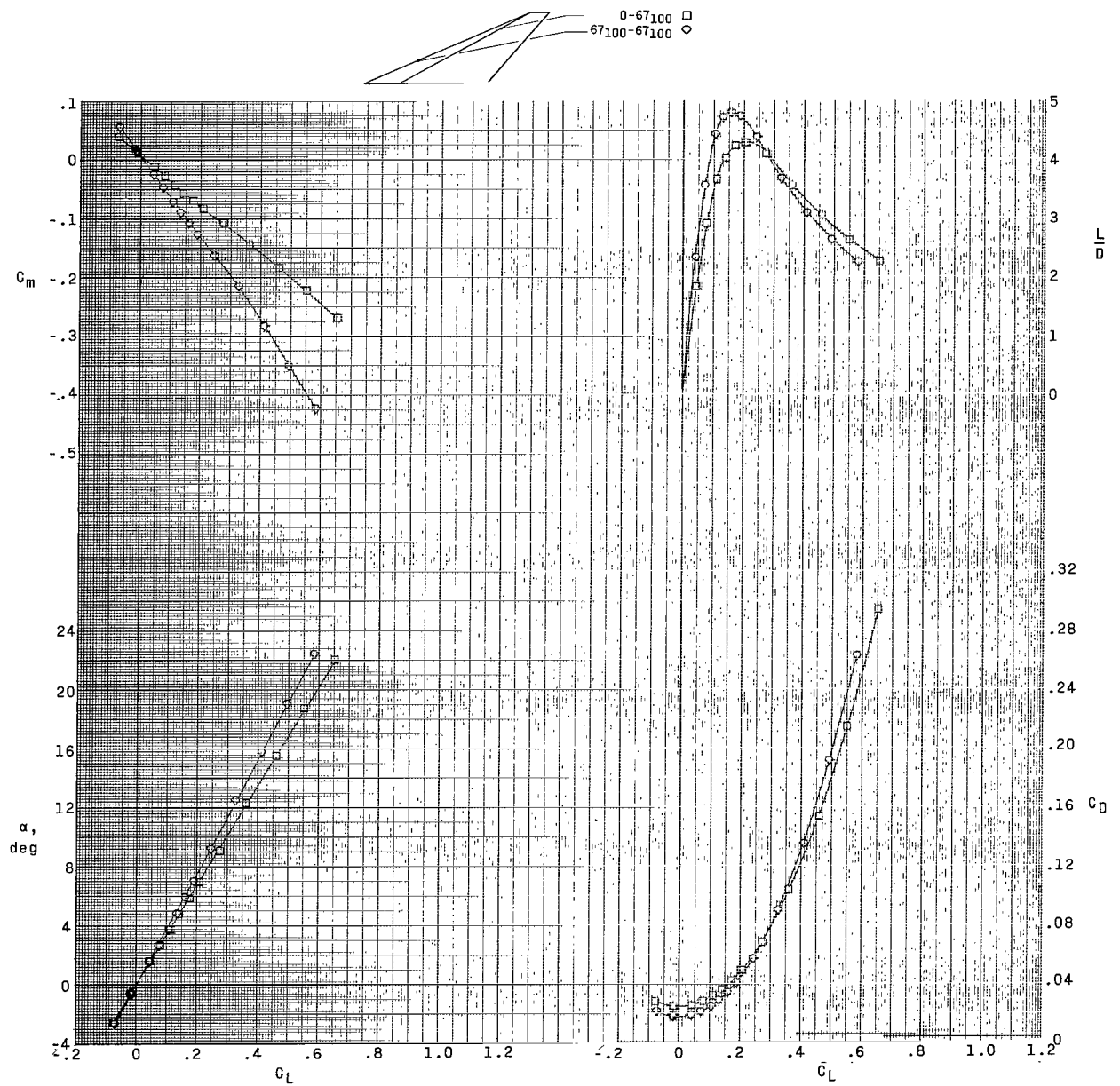
(a) $M = 1.70$.

Figure 4.- Effect of a full-span leading-edge extension on the longitudinal characteristics. Tail off. Data based on respective wing areas and referenced to respective 0.25C locations.



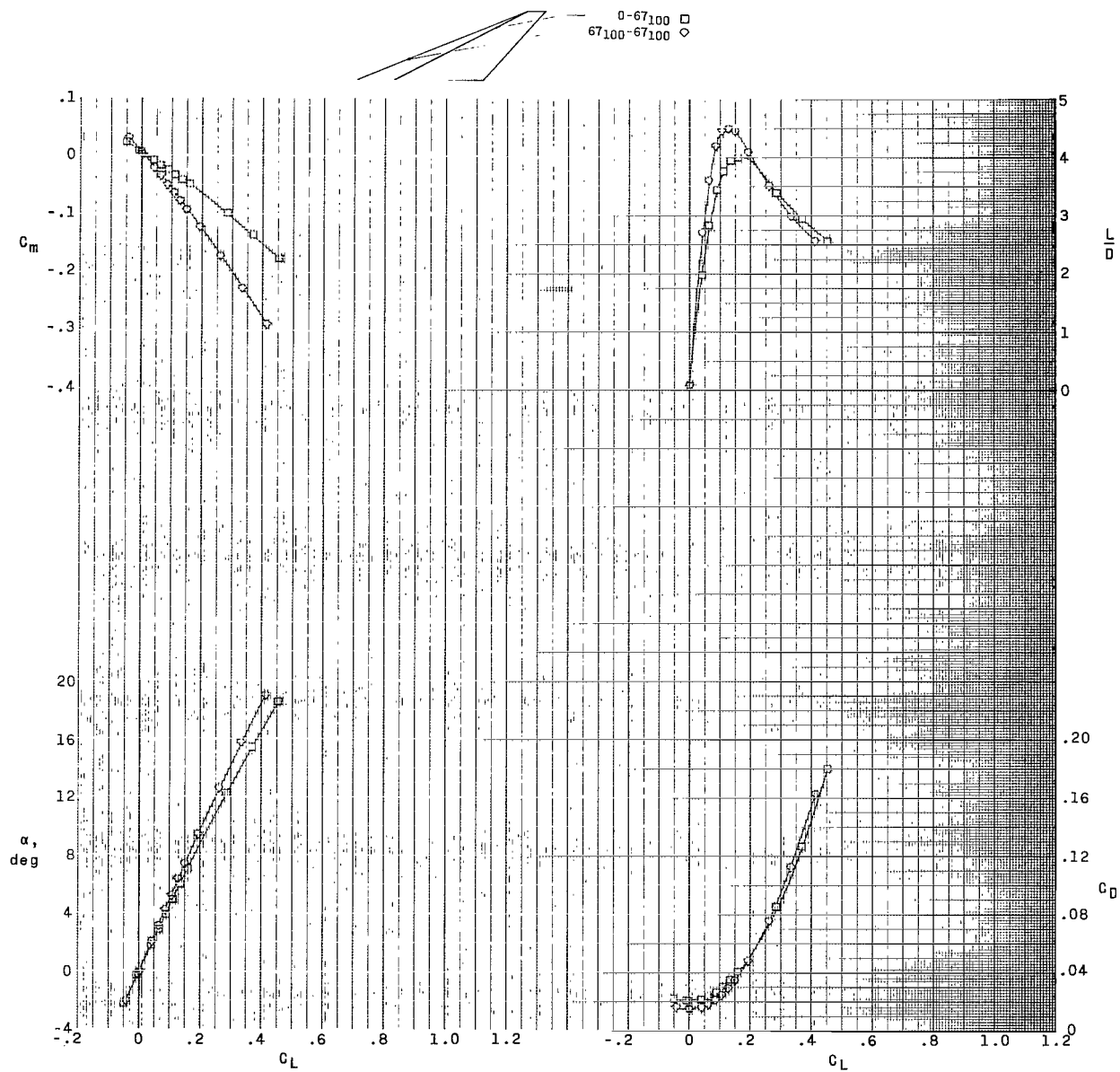
(b) $M = 2.16$.

Figure 4.- Continued.



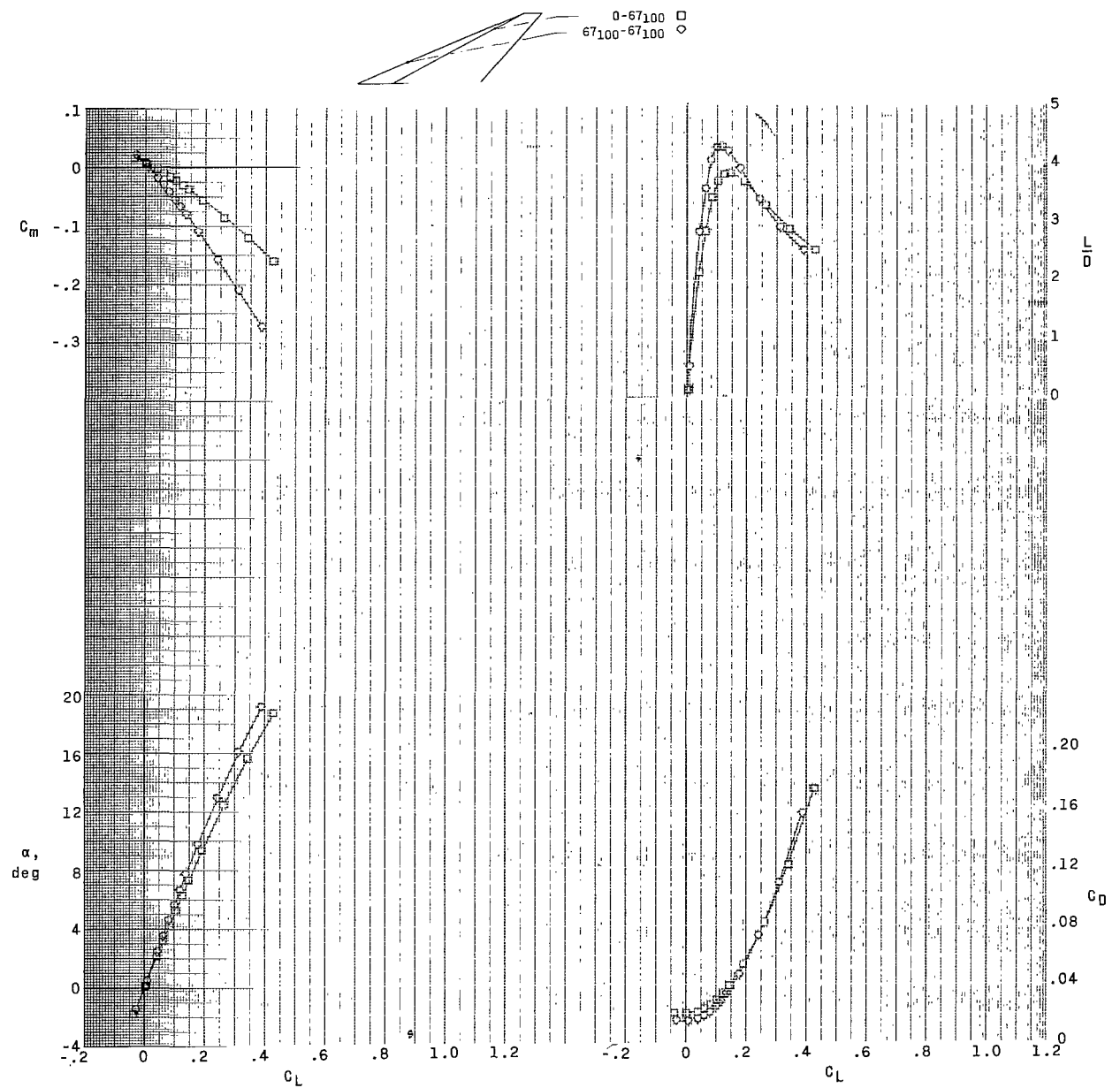
(c) $M = 2.87$.

Figure 4.- Continued.



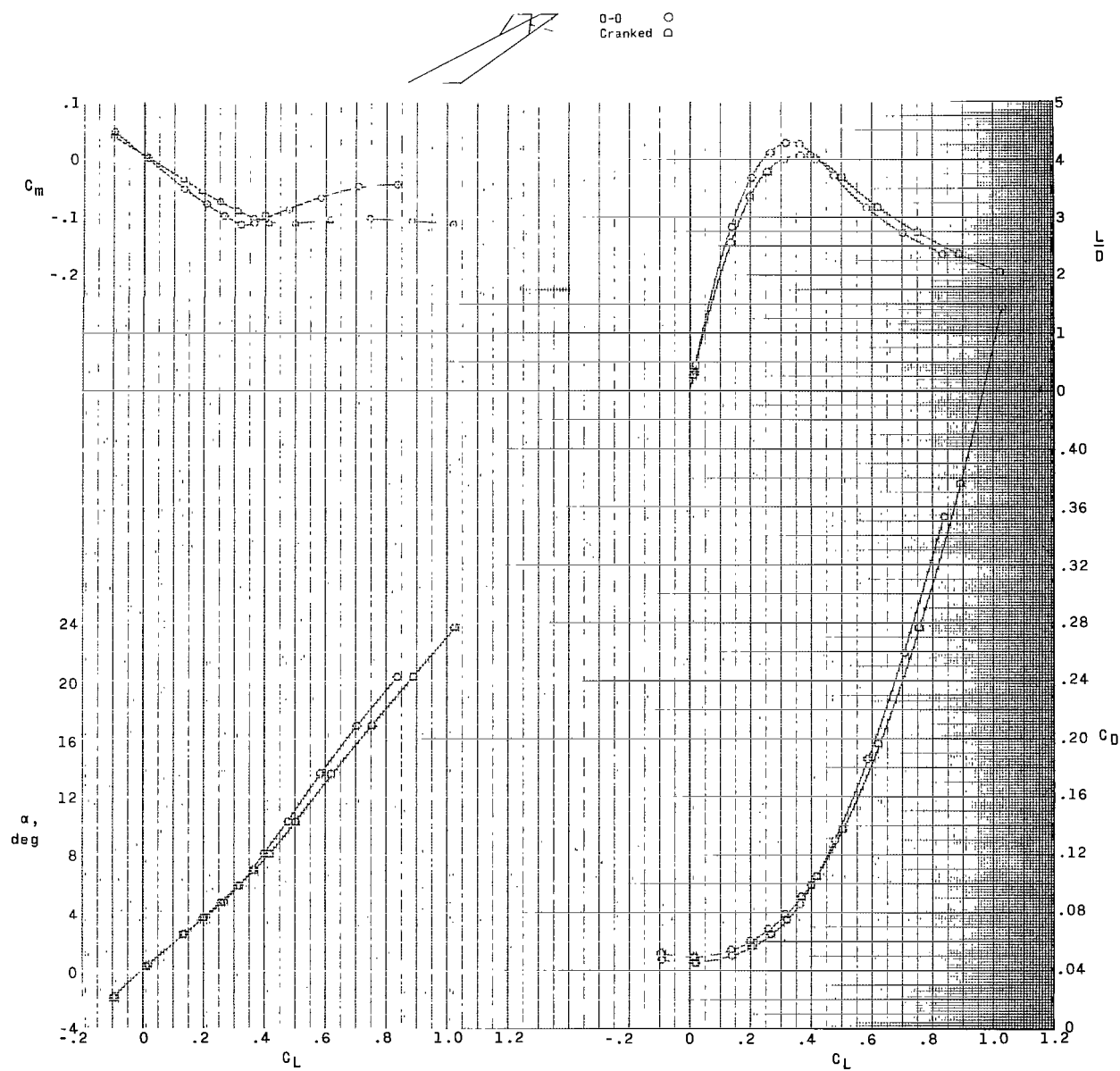
(d) $M = 3.96$.

Figure 4.- Continued.



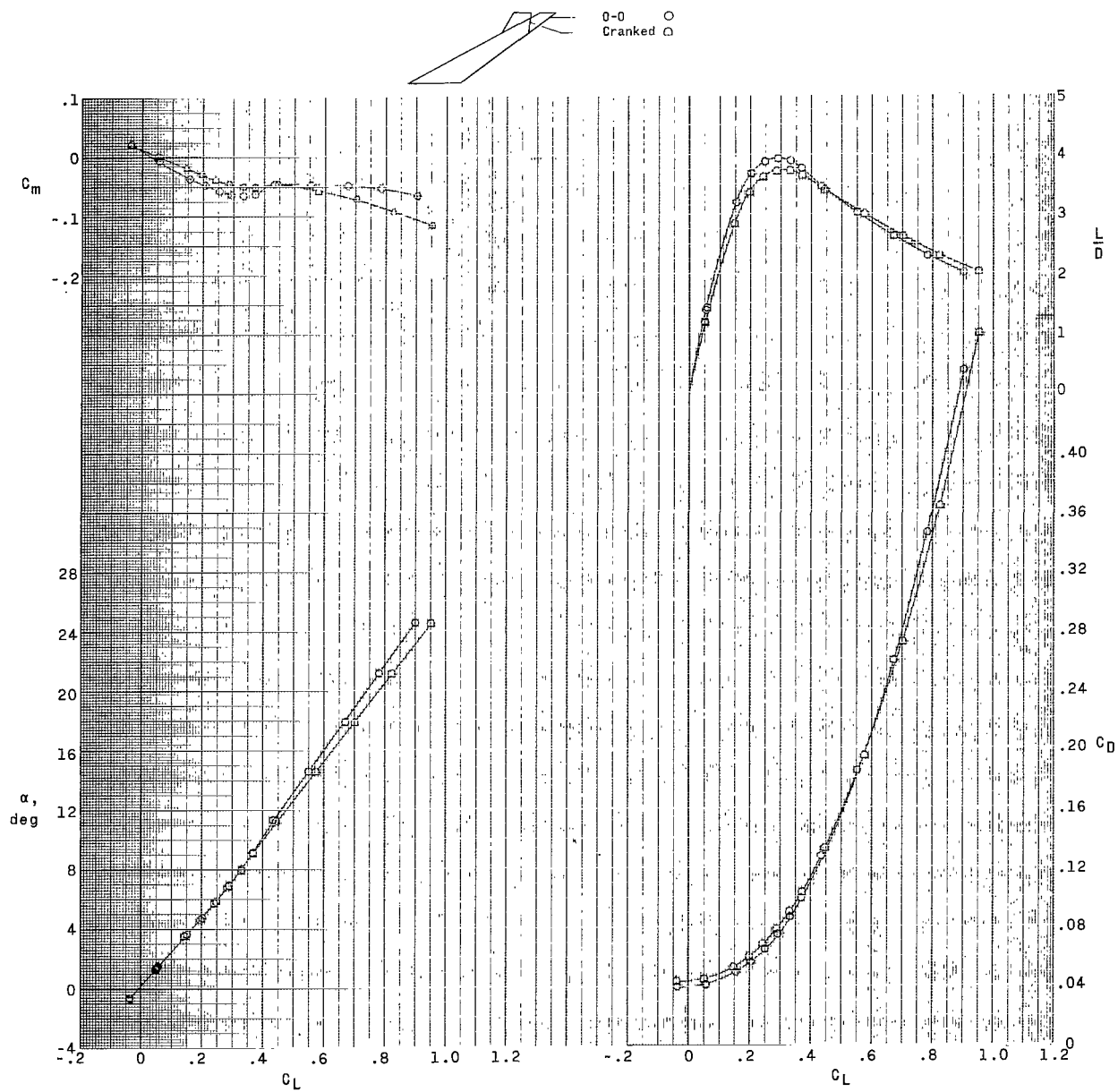
(e) $M = 4.63$.

Figure 4.- Concluded.



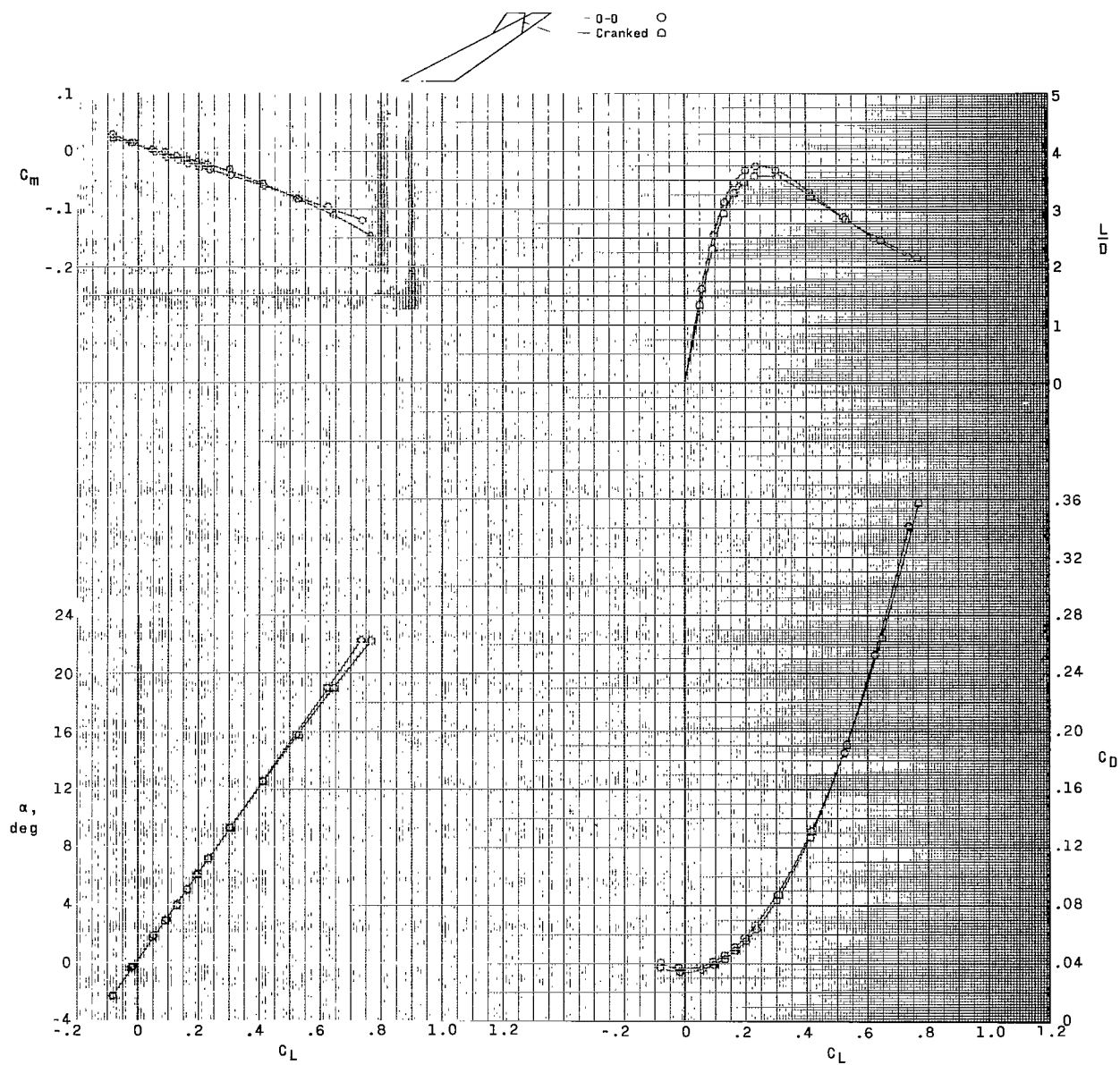
(a) $M = 1.70$.

Figure 5.- Effect of wing crank on the longitudinal characteristics. Tail off. Data based on respective wing areas and referenced to respective $0.25\bar{c}$ locations.



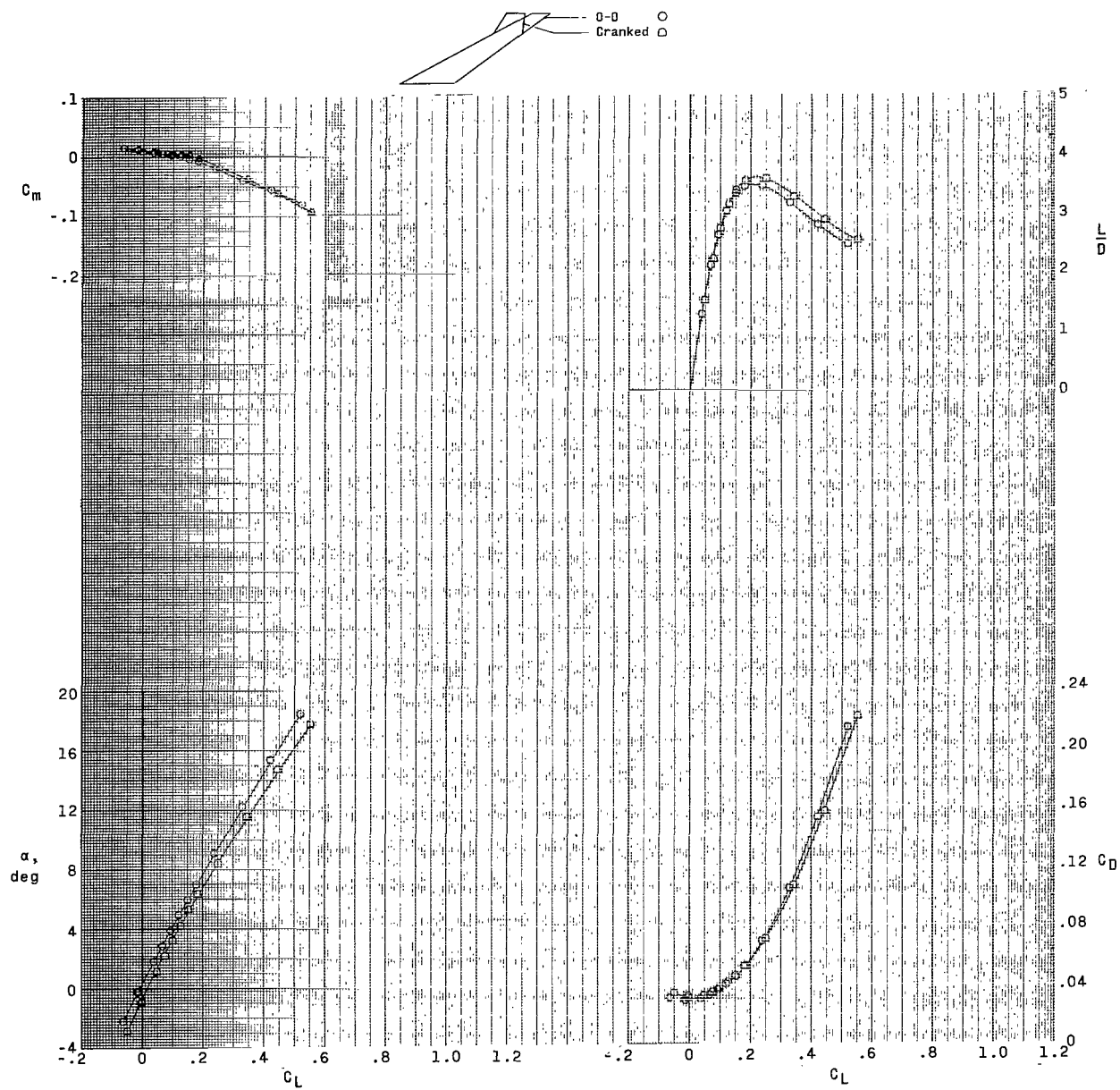
(b) $M = 2.16$.

Figure 5.- Continued.



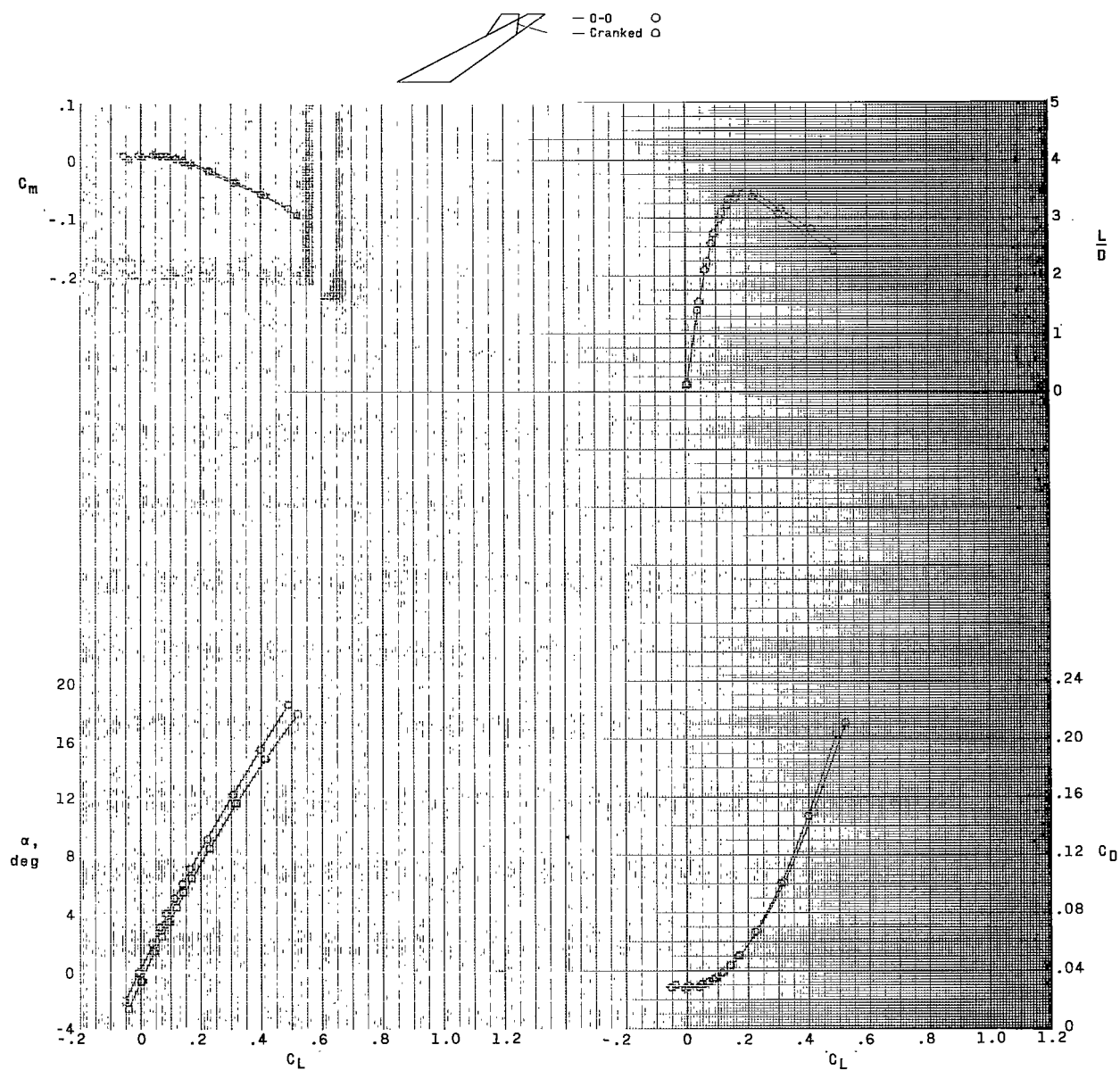
(c) $M = 2.87$.

Figure 5.- Continued.



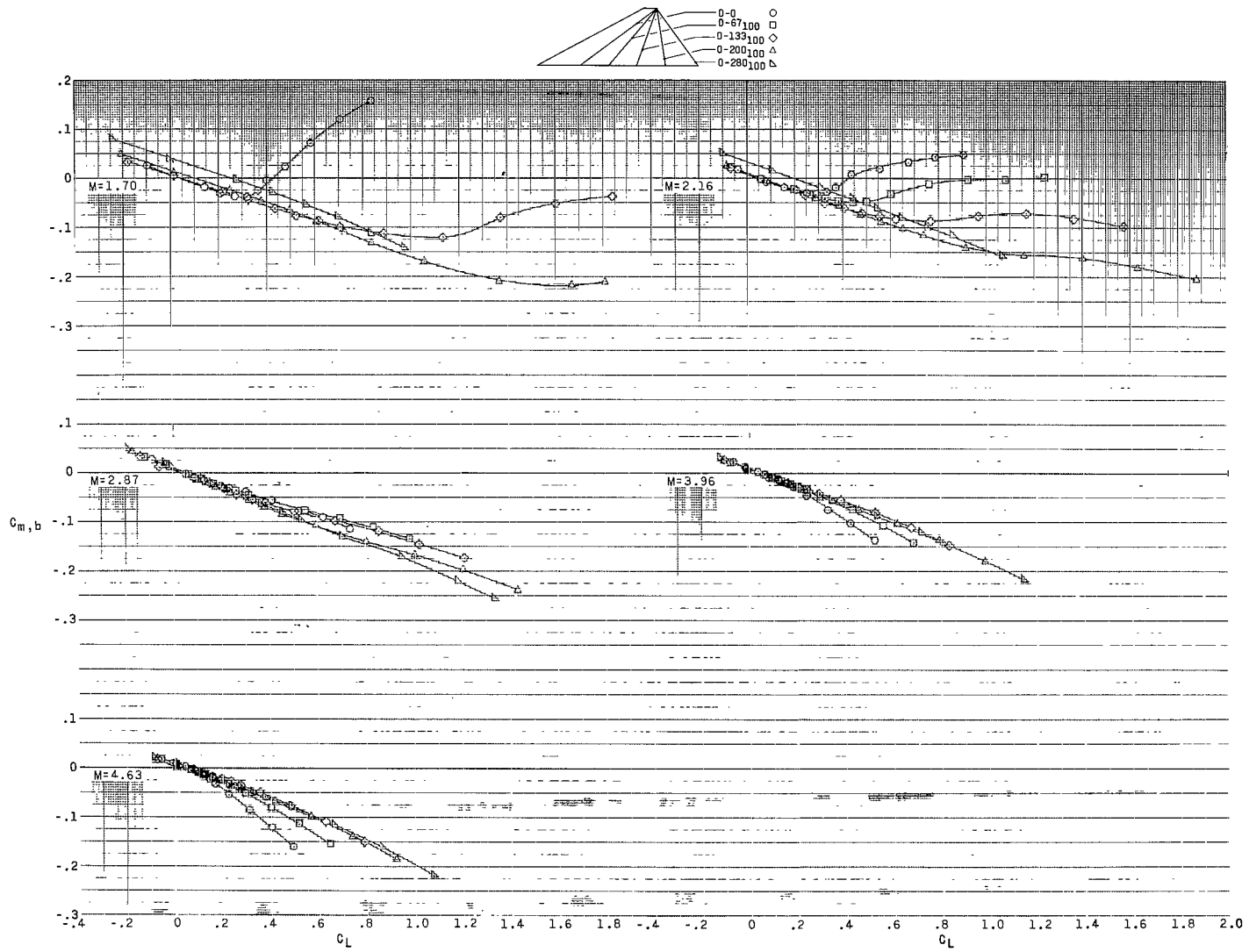
(d) $M = 3.96$.

Figure 5.- Continued.



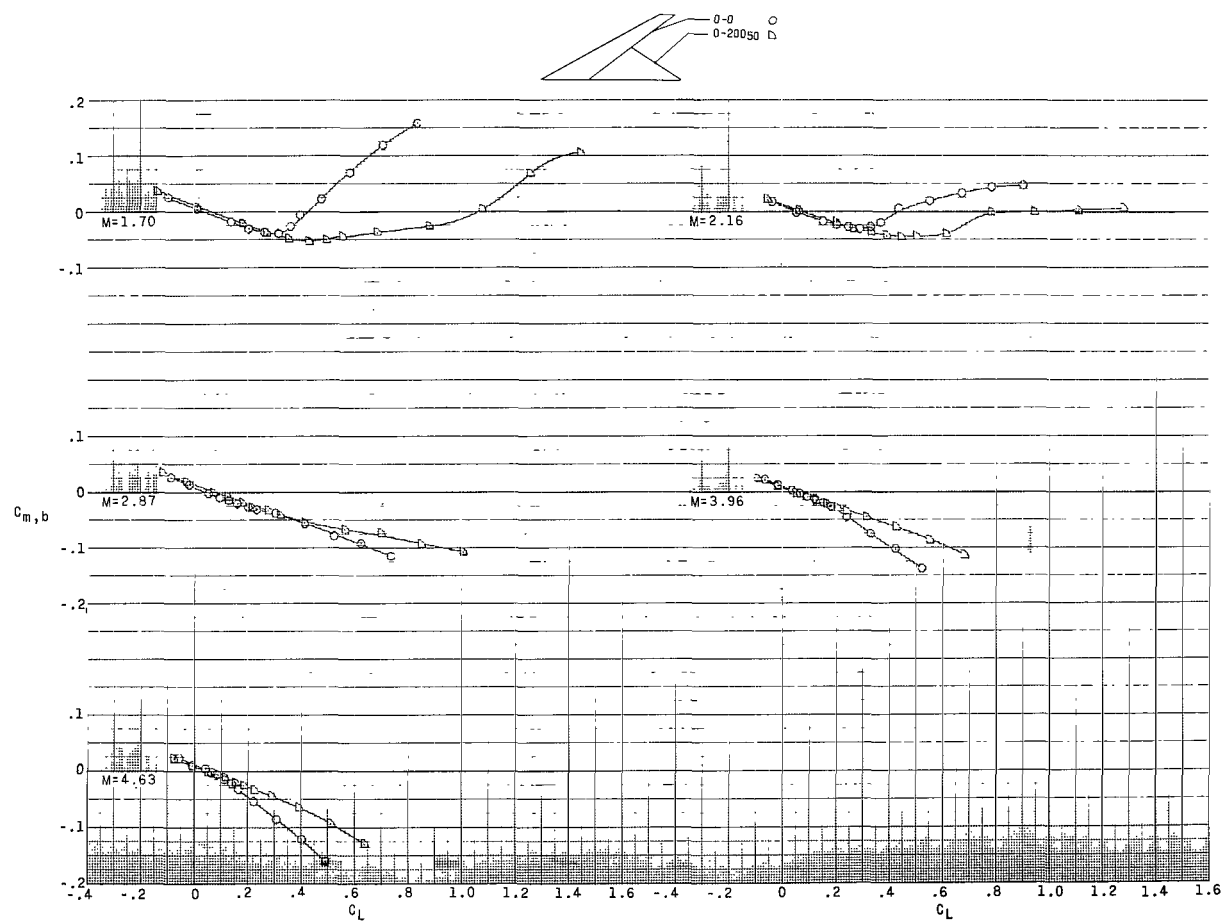
(e) $M = 4.63$.

Figure 5.- Concluded.



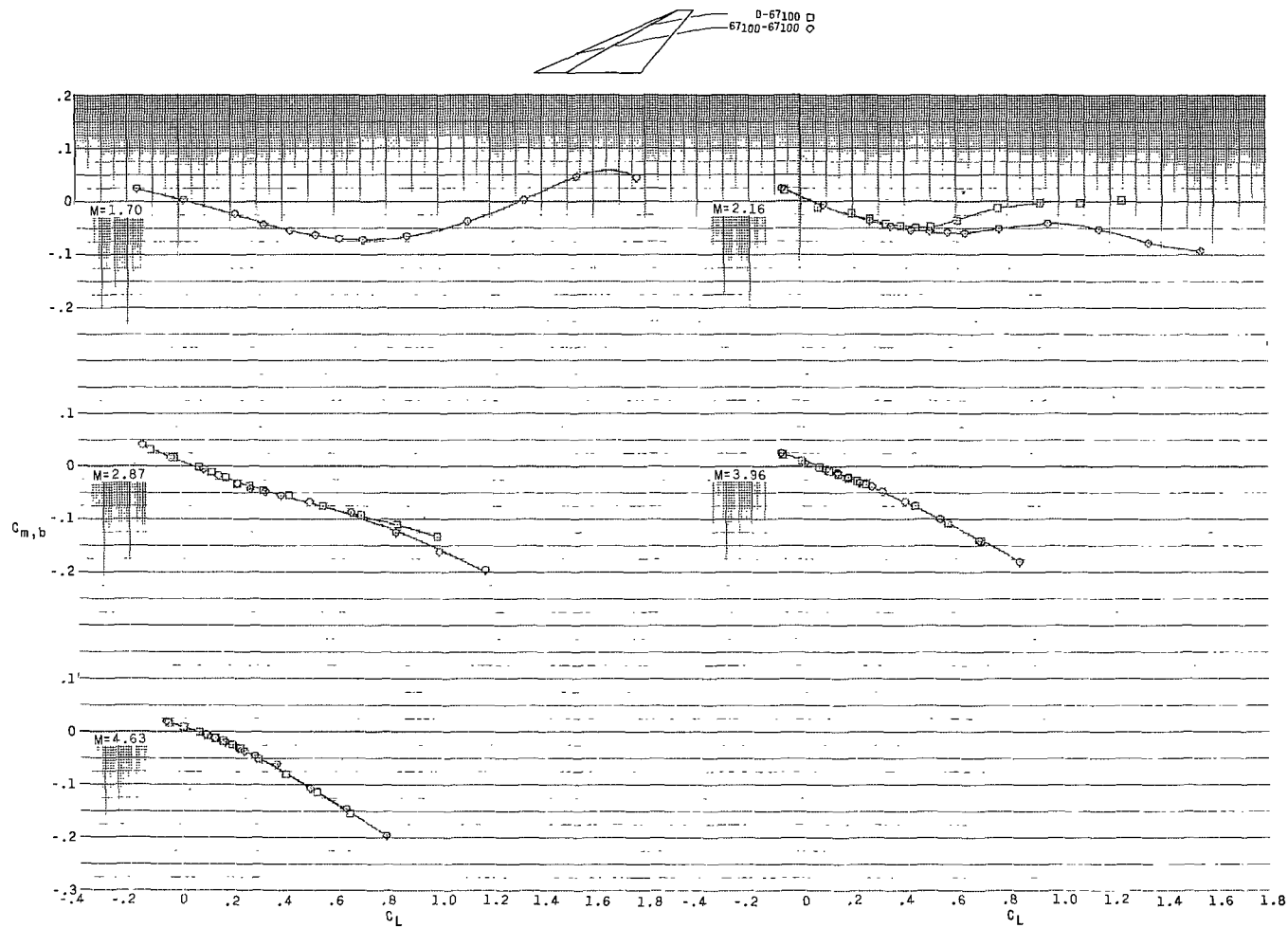
(a) Effect of full-span trailing-edge inserts.

Figure 6.- Pitching-moment characteristics based on the basic wing area for a static margin of 1 inch.



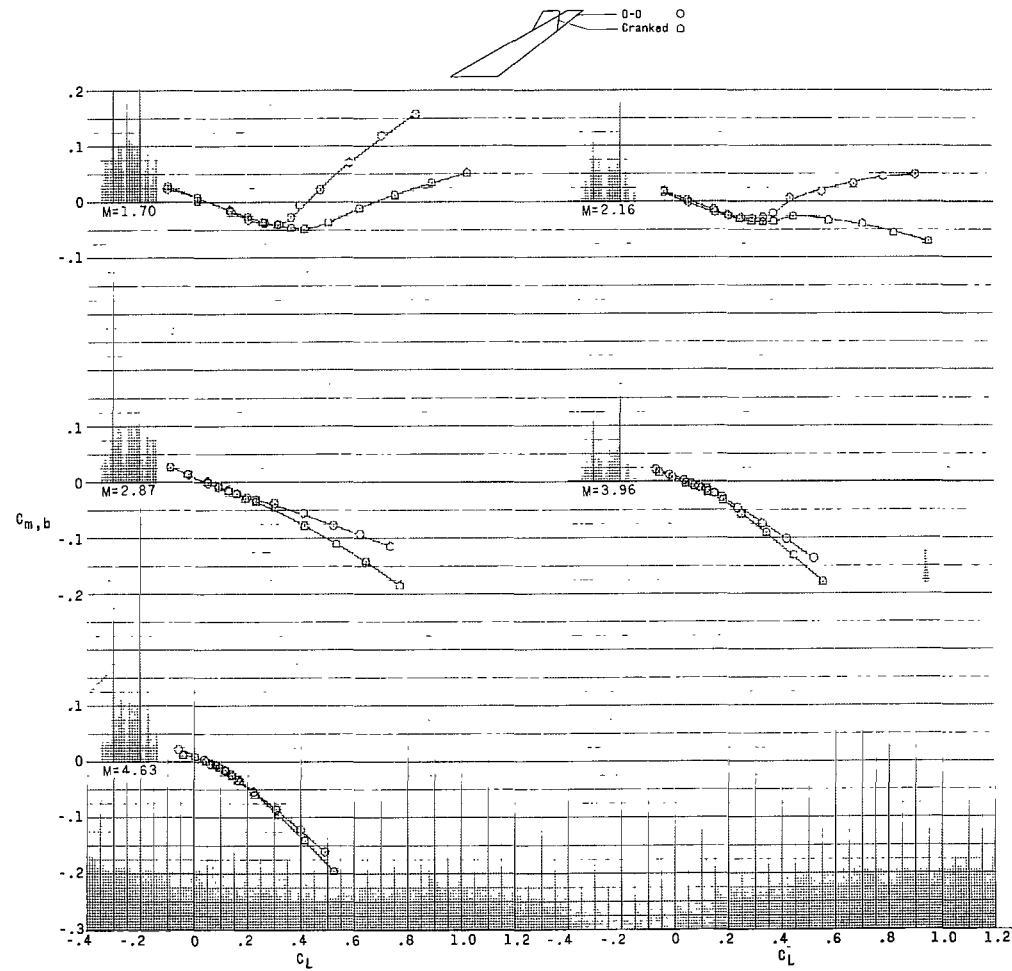
(b) Effect of a semispan trailing-edge insert.

Figure 6.- Continued.



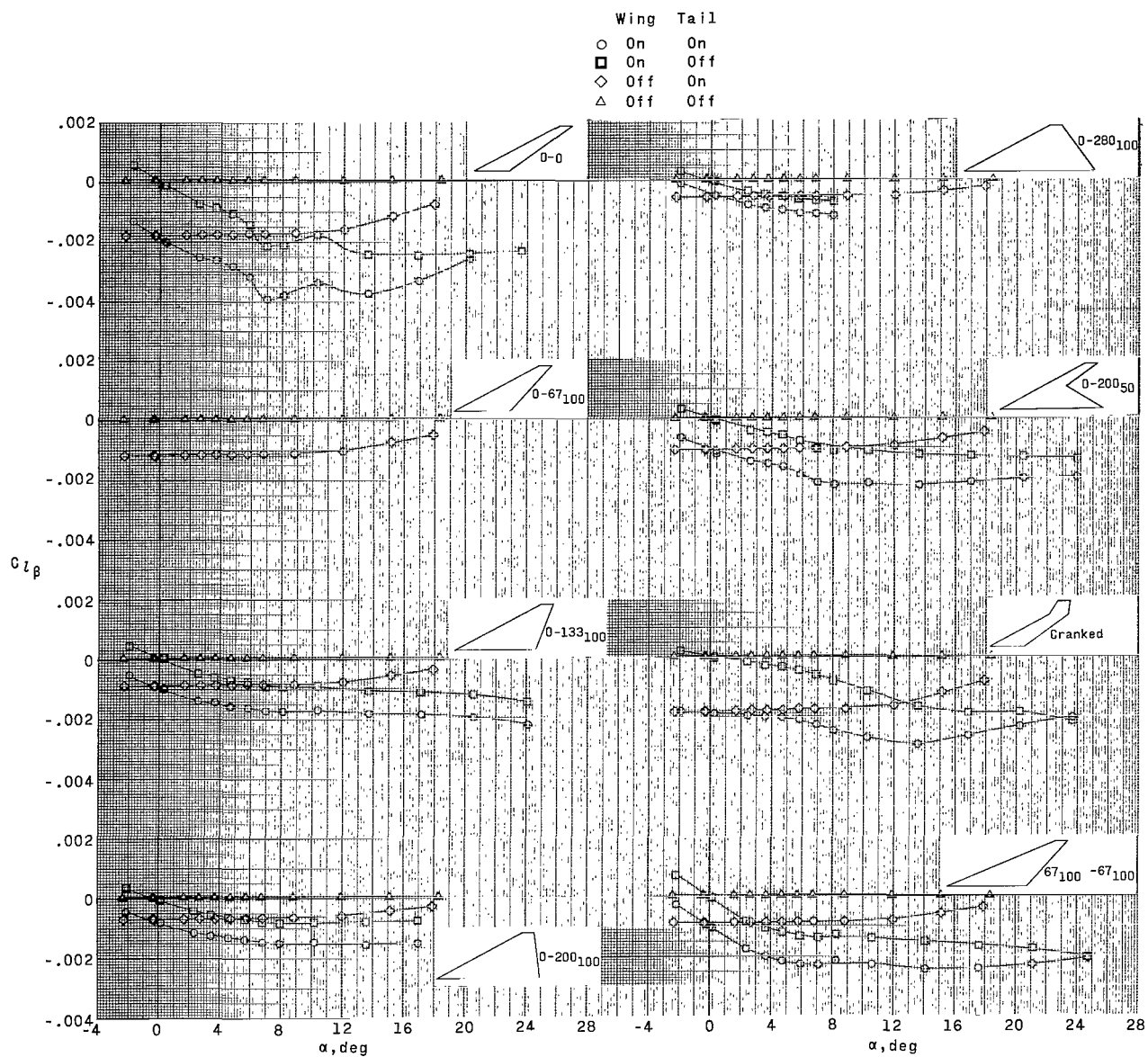
(c) Effect of a full-span leading-edge extension.

Figure 6.- Continued.



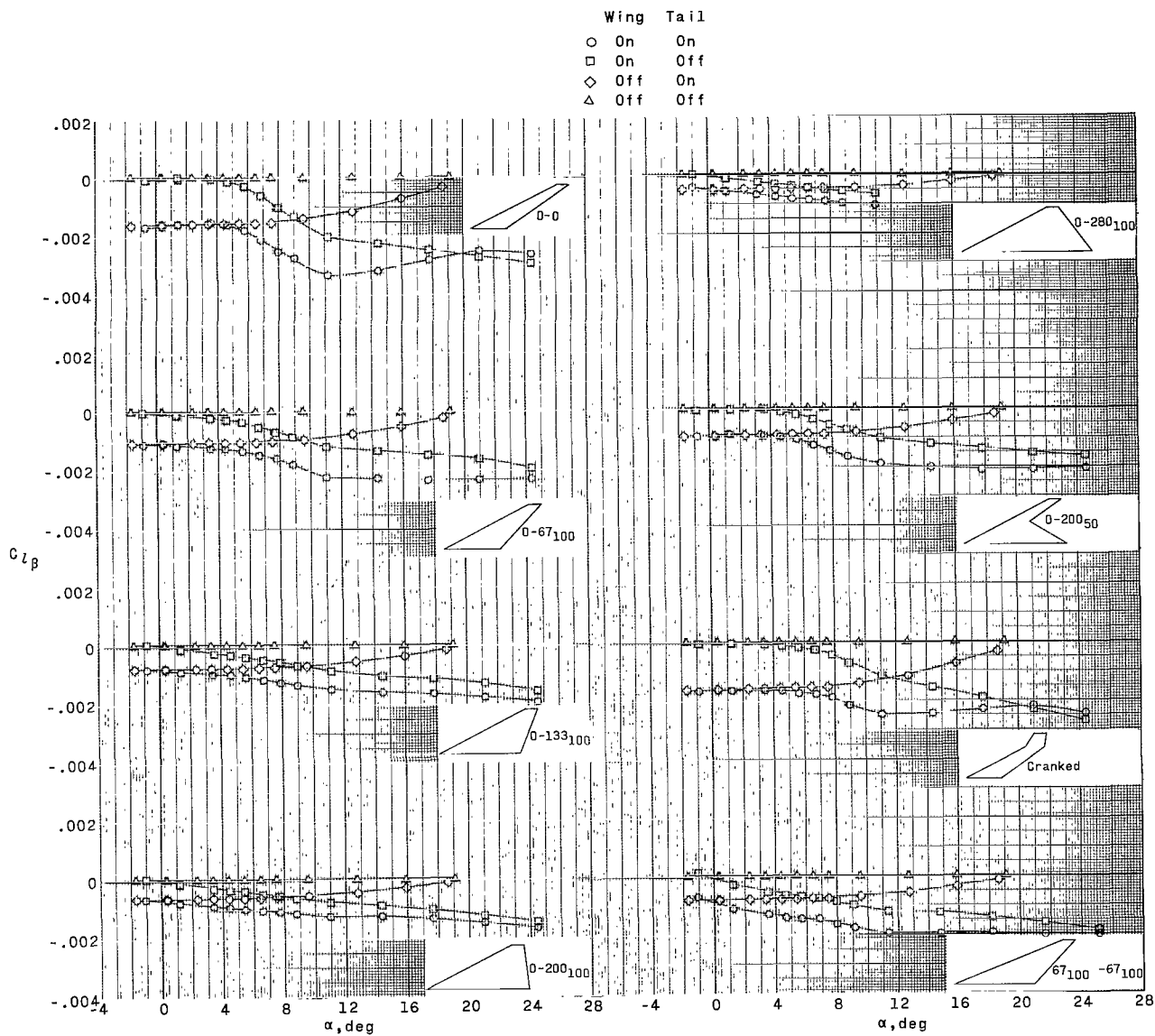
(d) Effect of cranked-wing tip.

Figure 6.- Concluded.



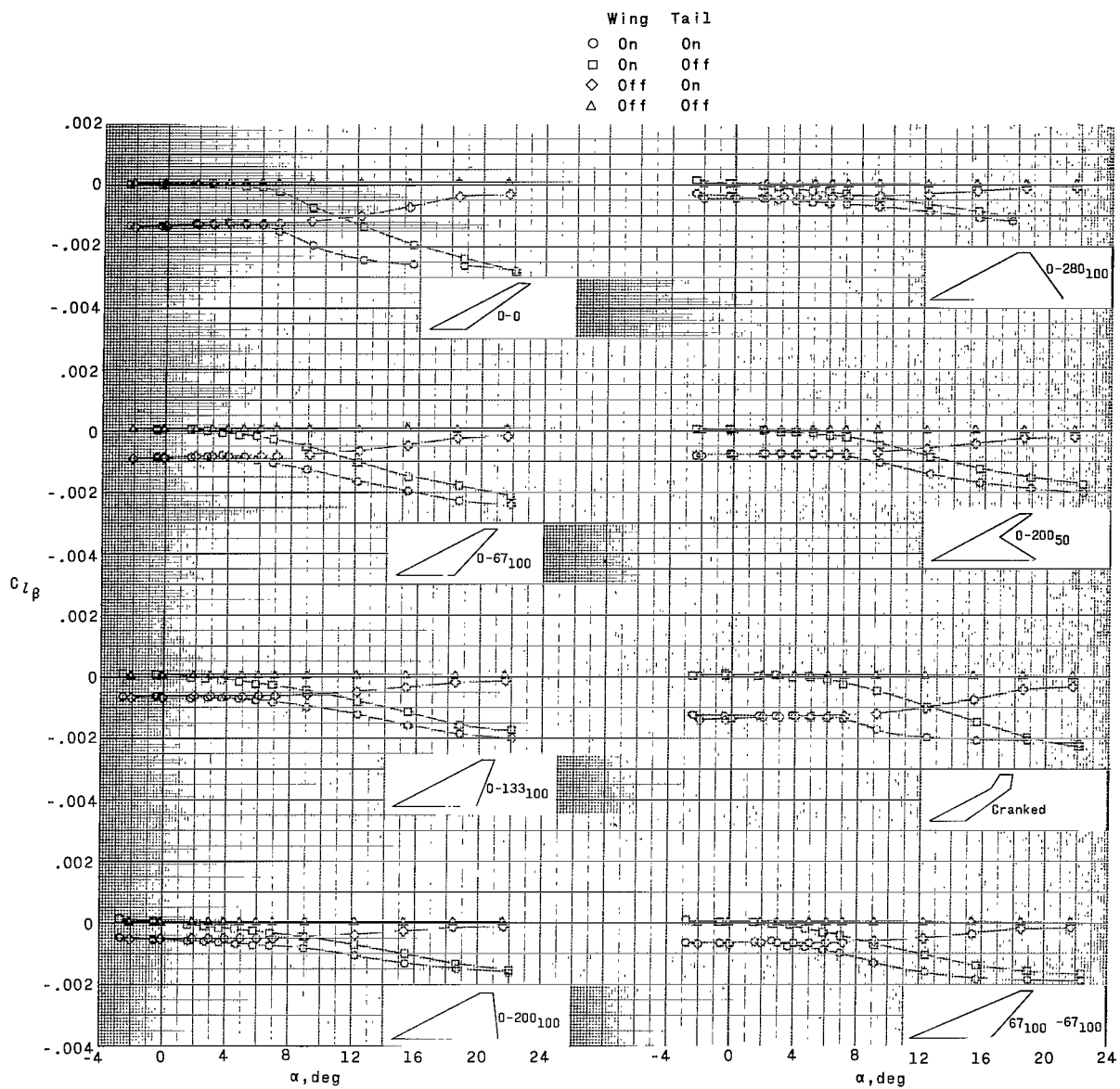
(a) $M = 1.70$.

Figure 7.- Variation of $C_{L\beta}$ with angle of attack. Data based on respective wing areas and referenced to balance moment center.



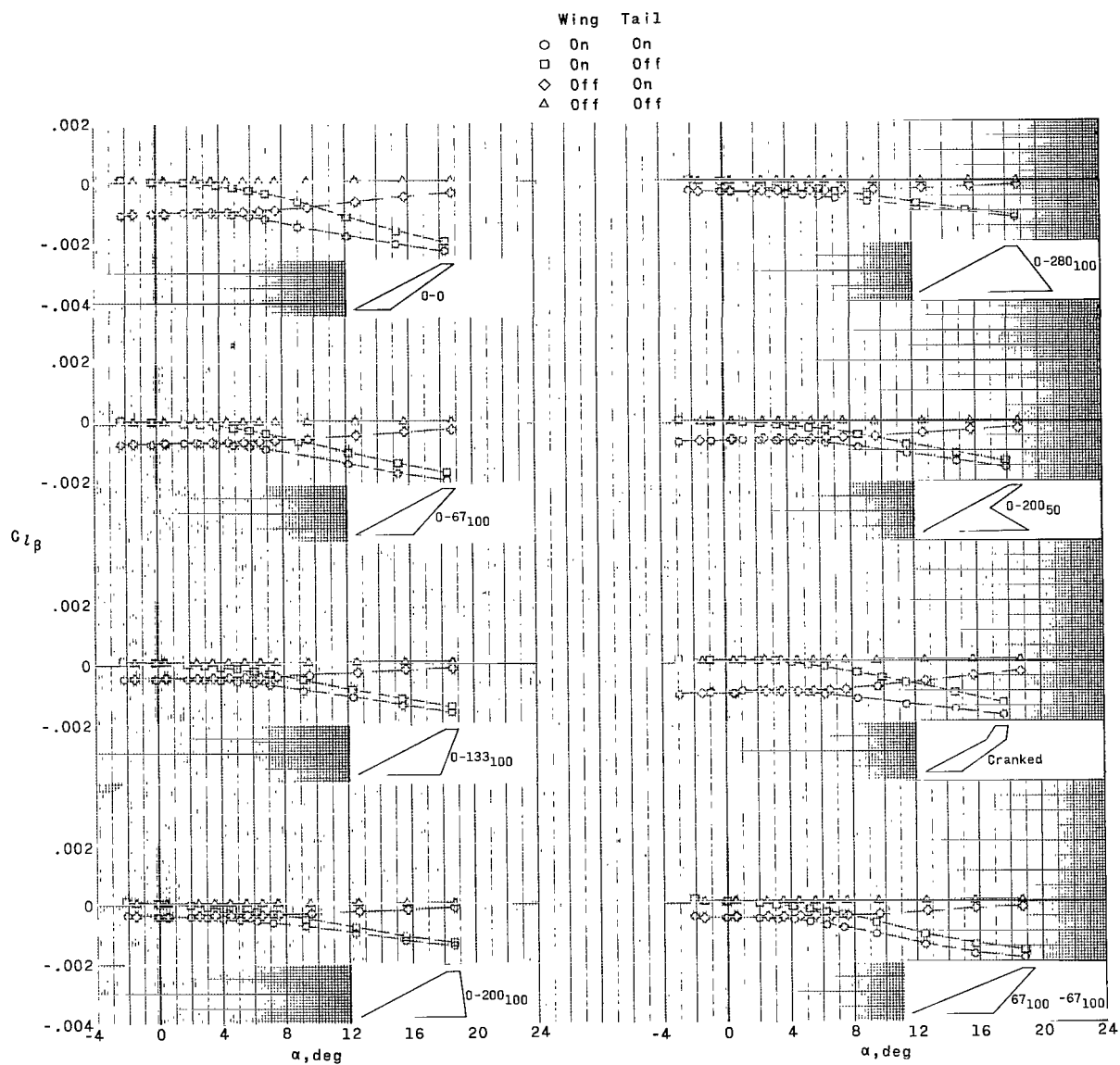
(b) $M = 2.16$.

Figure 7.- Continued.



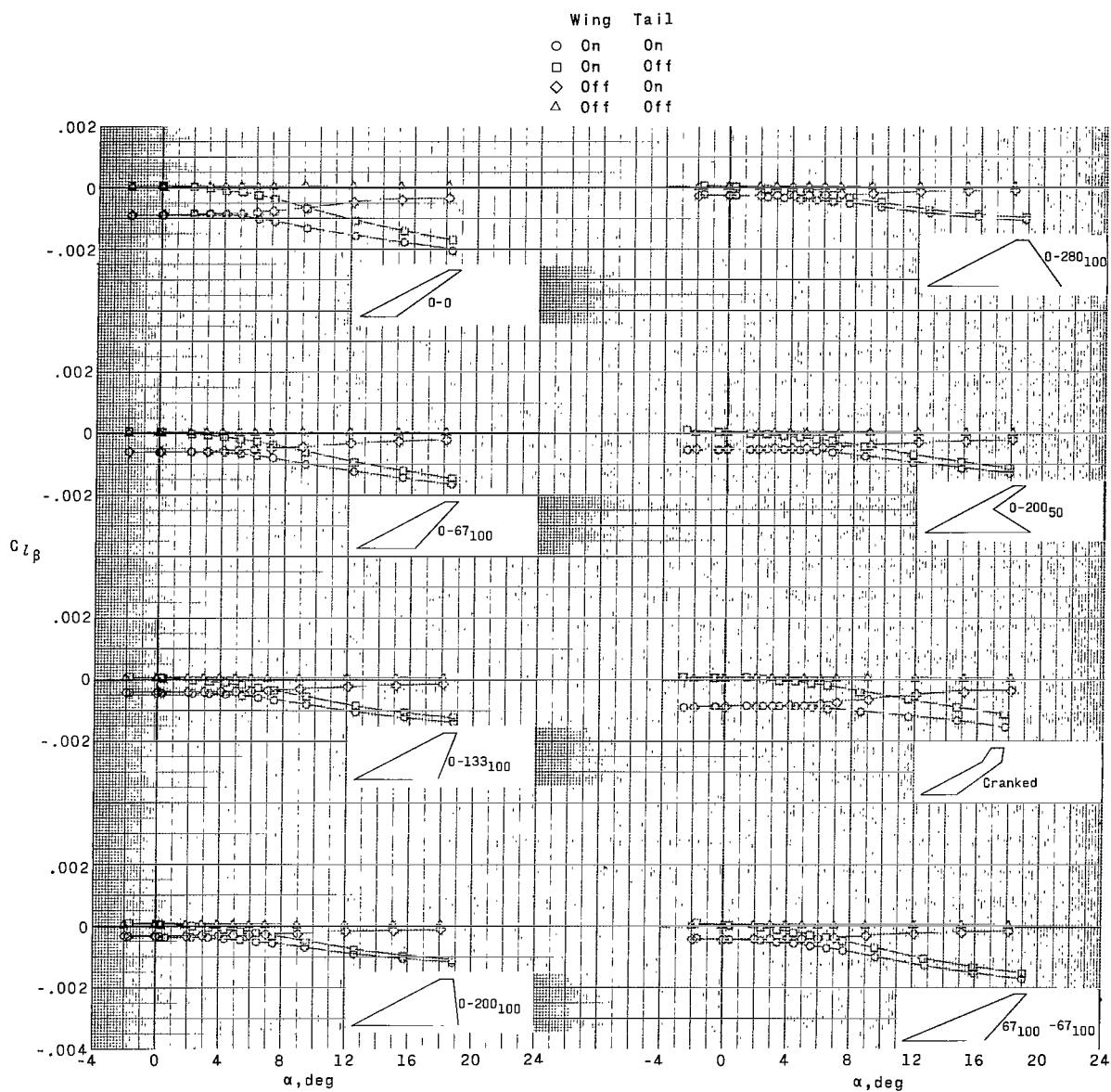
(c) $M = 2.87$.

Figure 7.- Continued.



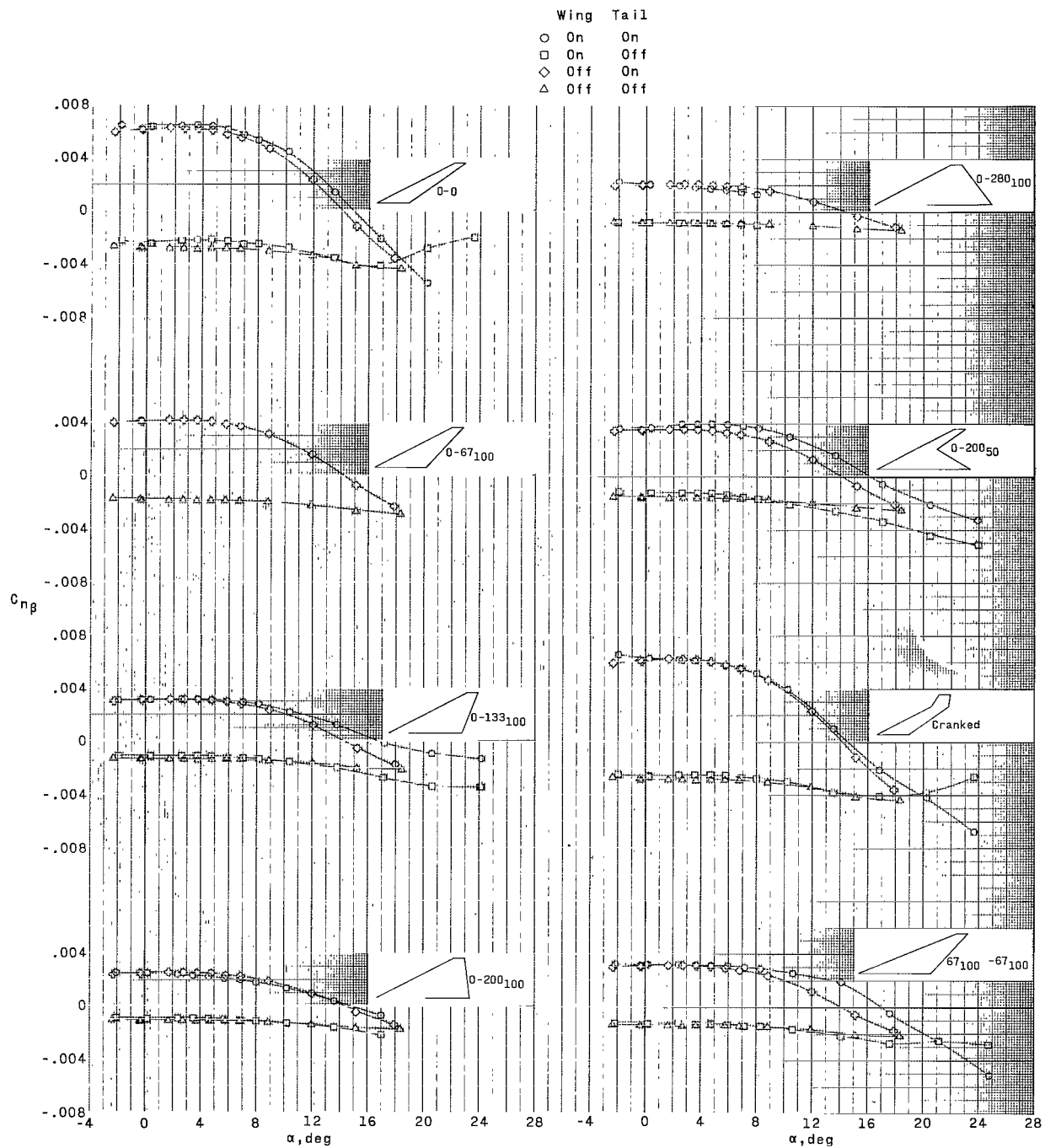
(d) $M = 3.96$.

Figure 7.- Continued.



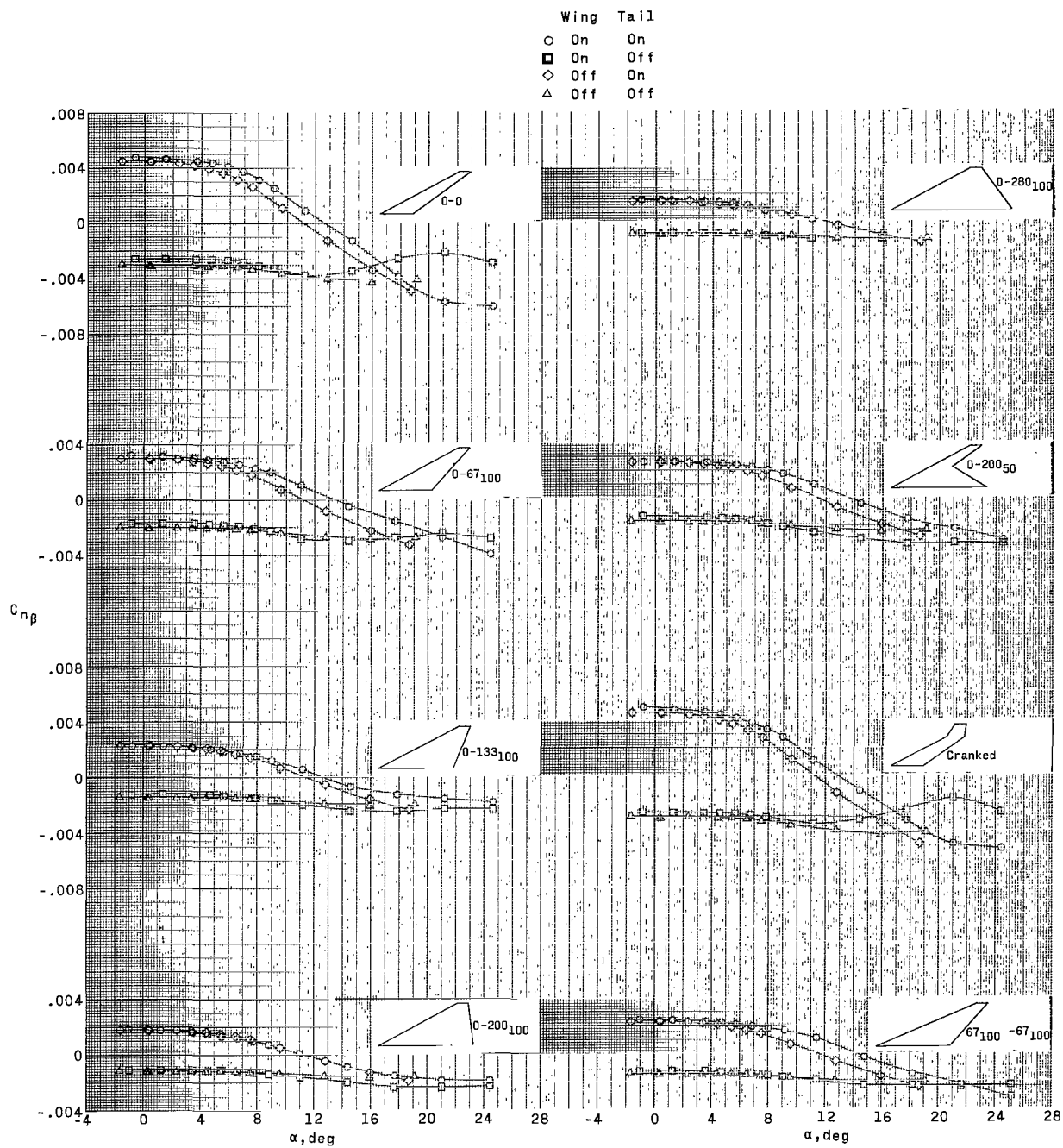
(e) $M = 4.63$.

Figure 7.- Concluded.



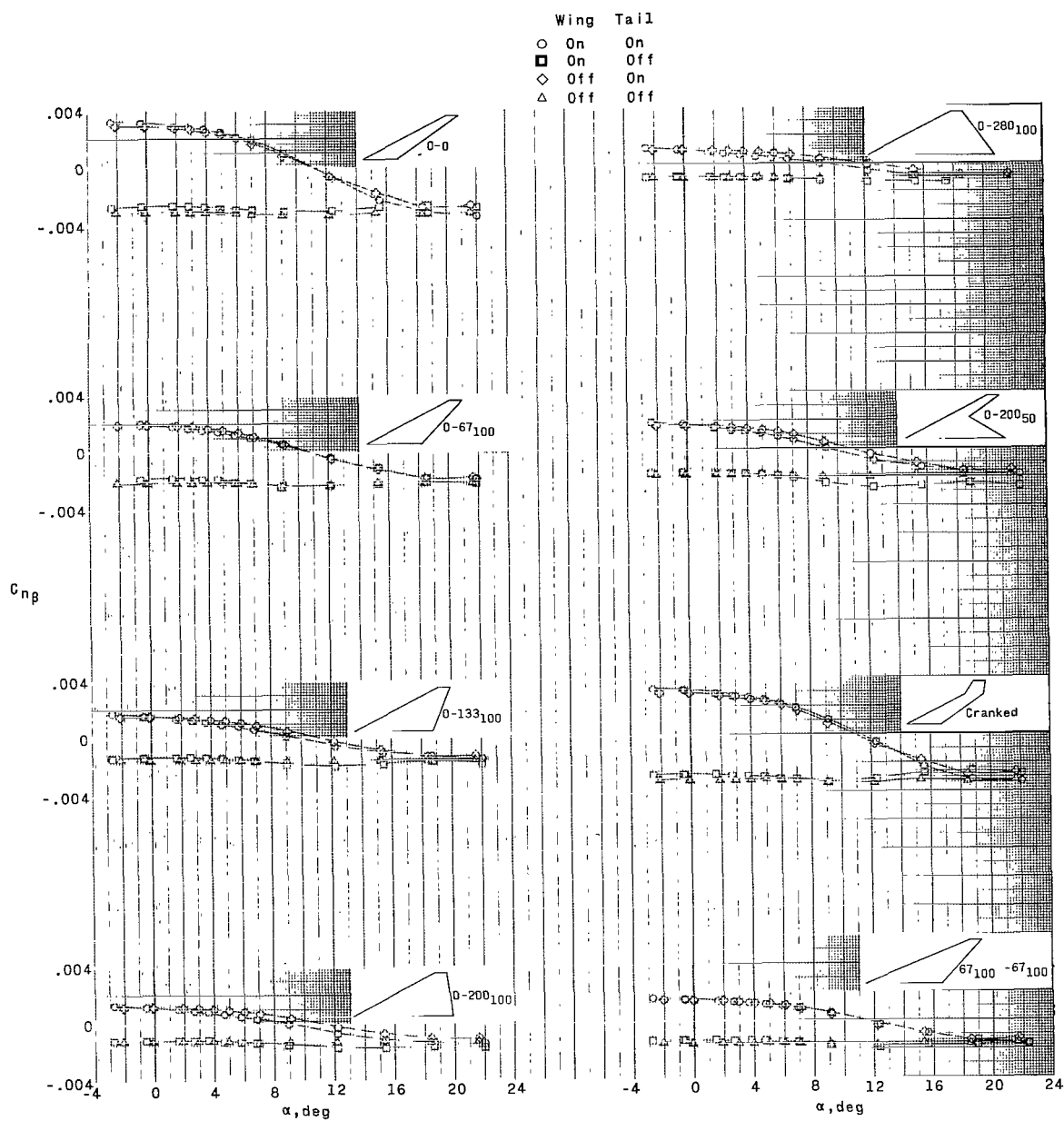
(a) $M = 1.70$.

Figure 8.- Variation of $C_{n\beta}$ with angle of attack. Data based on respective wing areas and referenced to balance moment center.



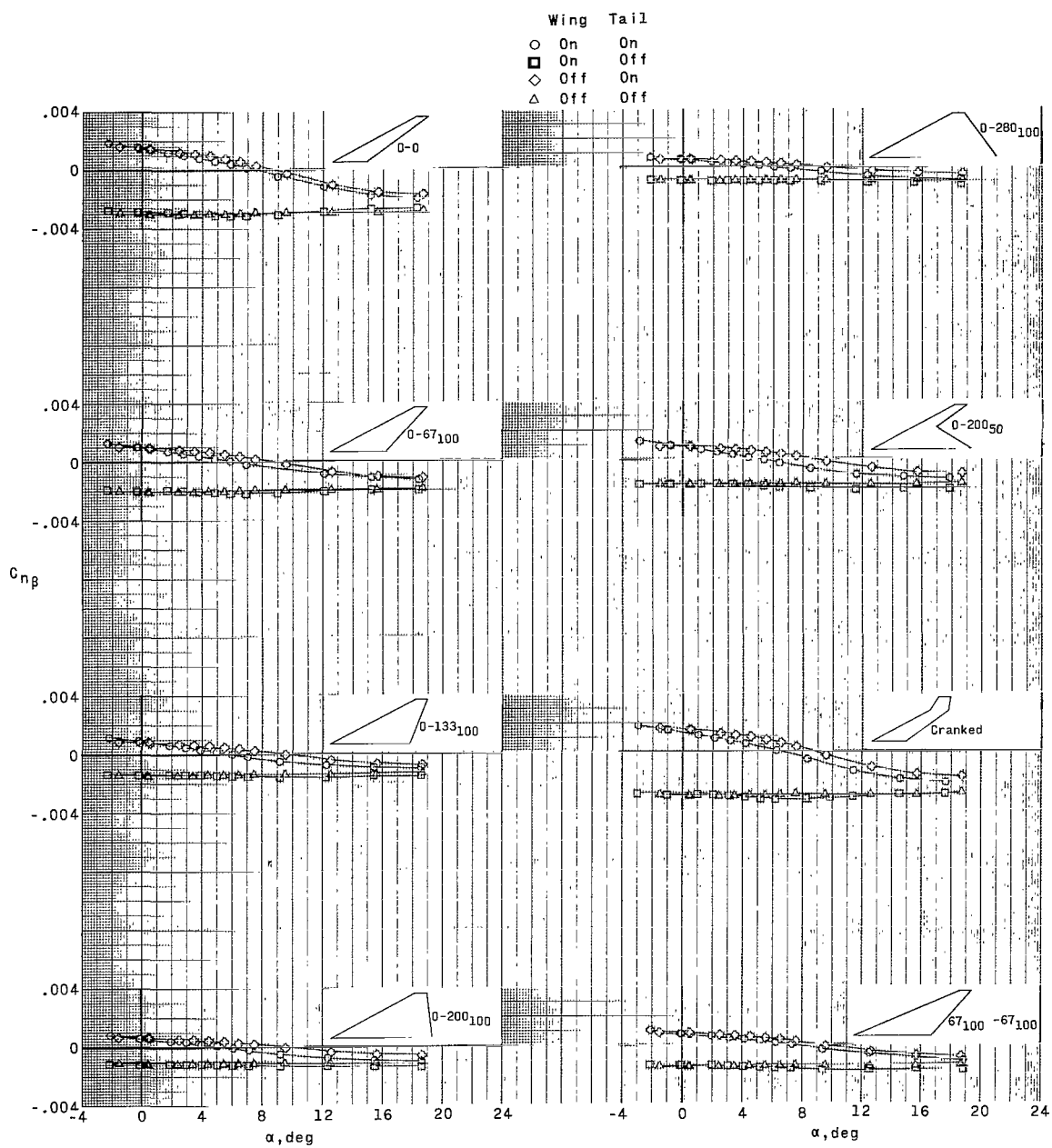
(b) $M = 2.16$.

Figure 8.- Continued.



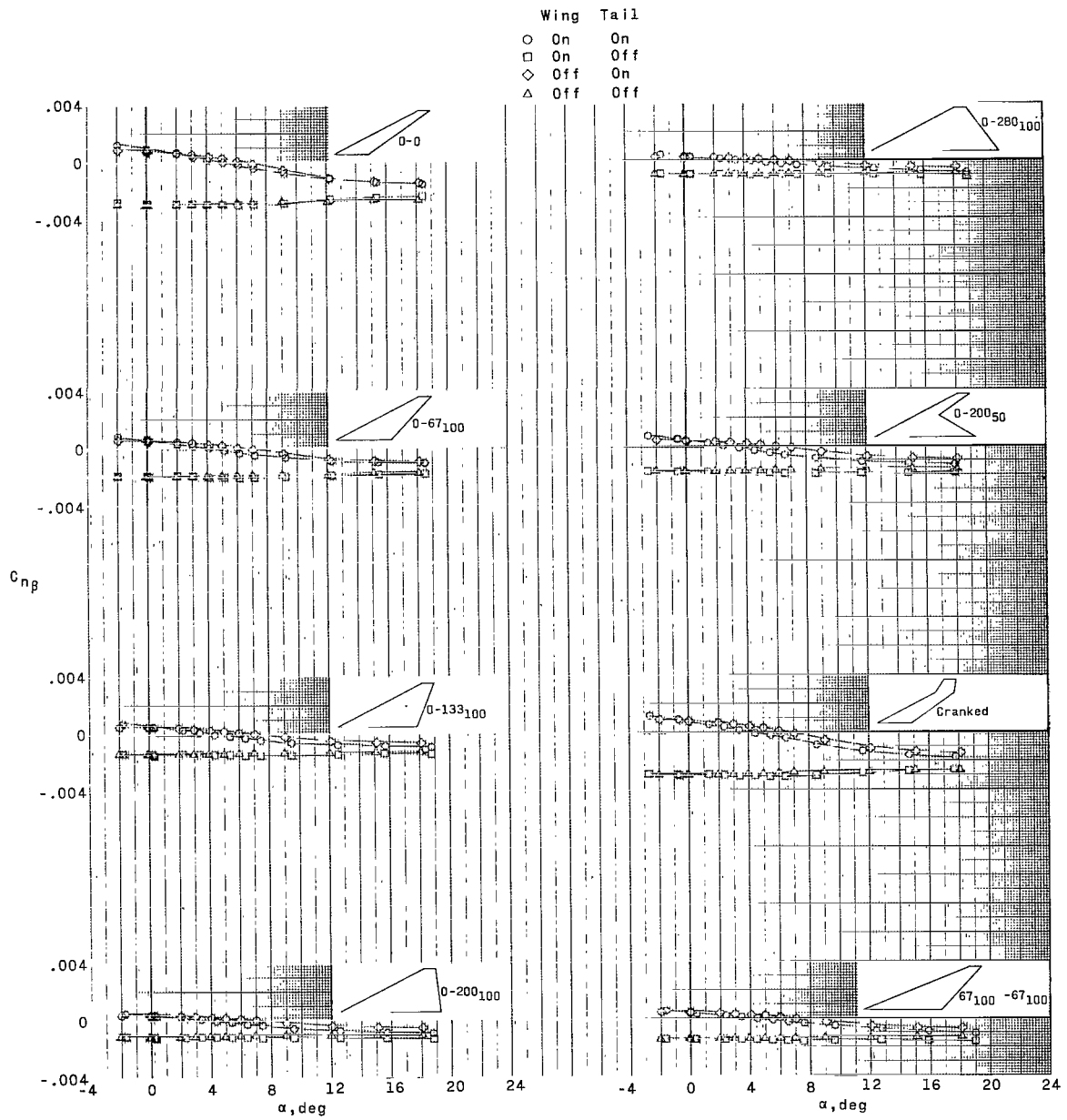
(c) $M = 2.87$.

Figure 8.- Continued.



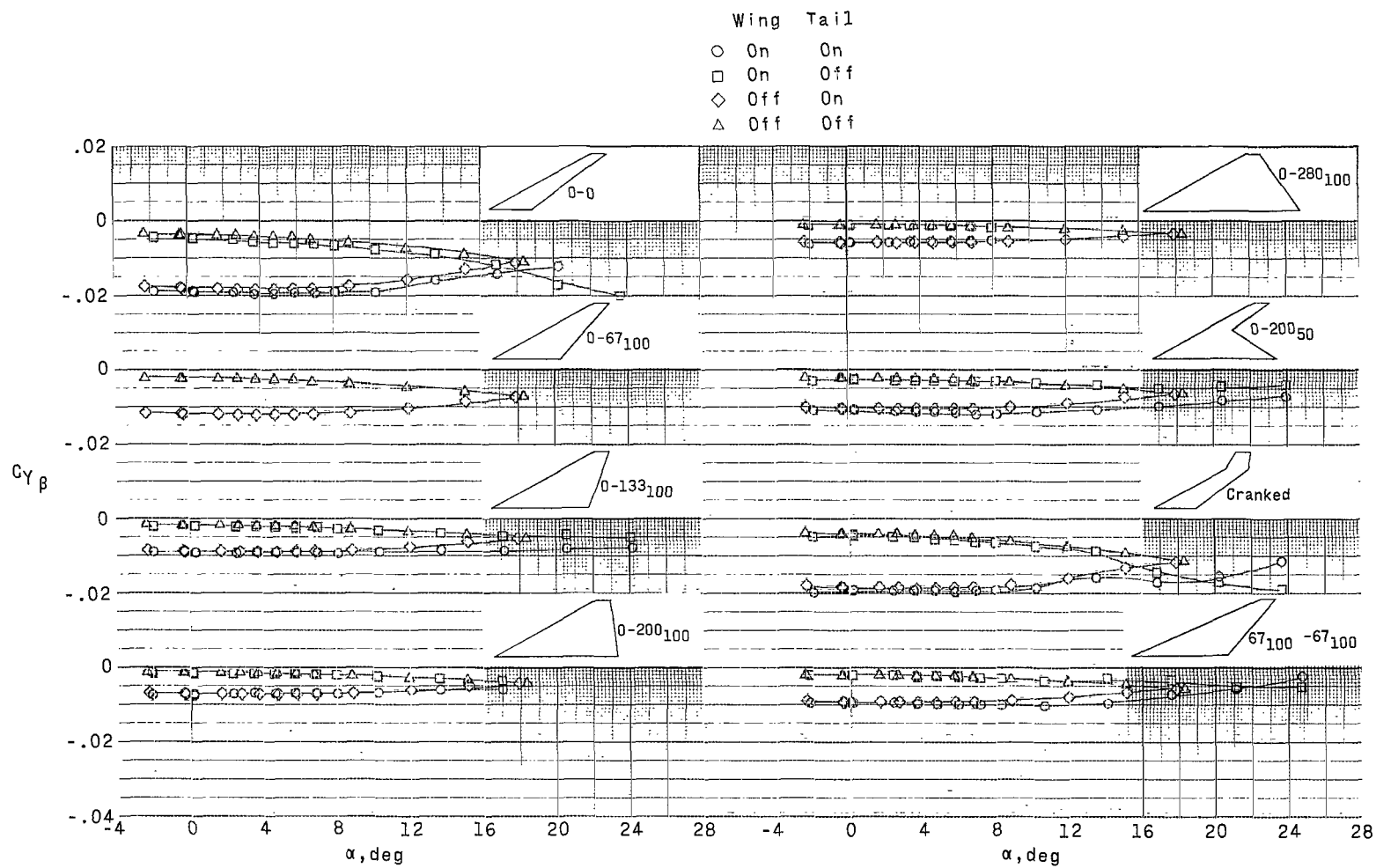
(d) $M = 3.96$.

Figure 8.- Continued.



(e) $M = 4.63$.

Figure 8.- Concluded.

(a) $M = 1.70$.Figure 9.- Variation of $C_{Y\beta}$ with angle of attack. Data based on respective wing areas and referenced to balance moment center.

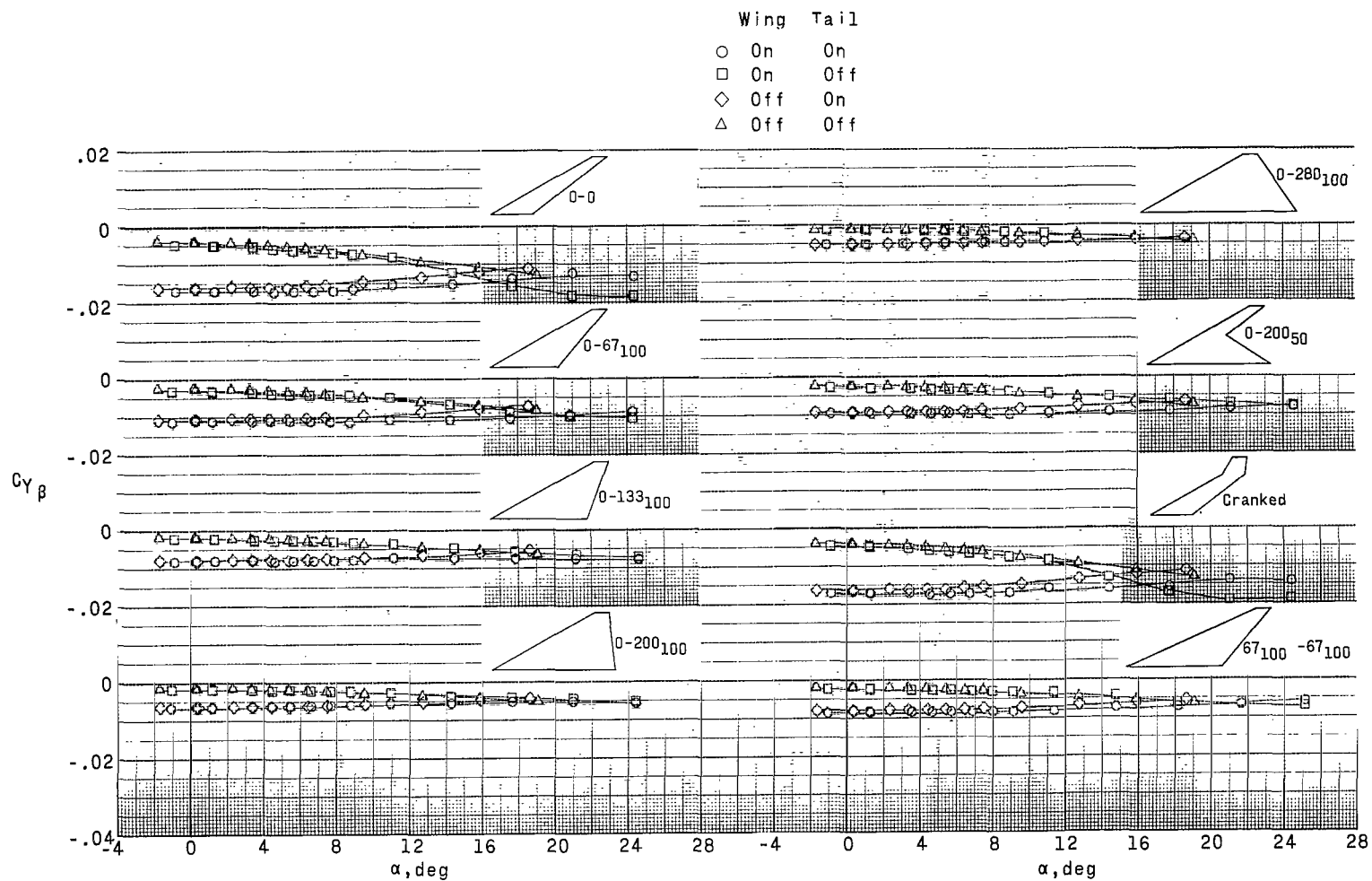


Figure 9.- Continued.

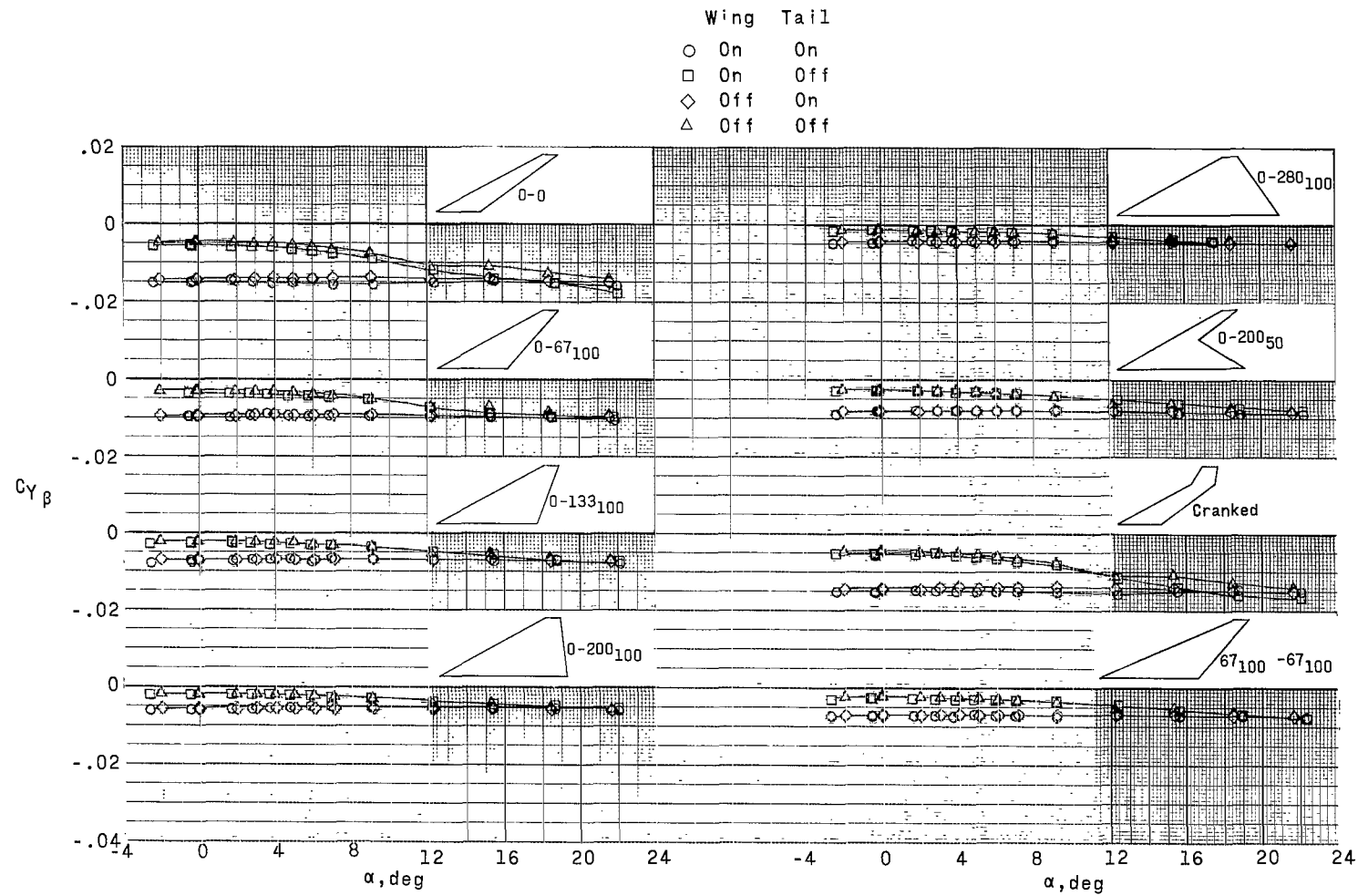
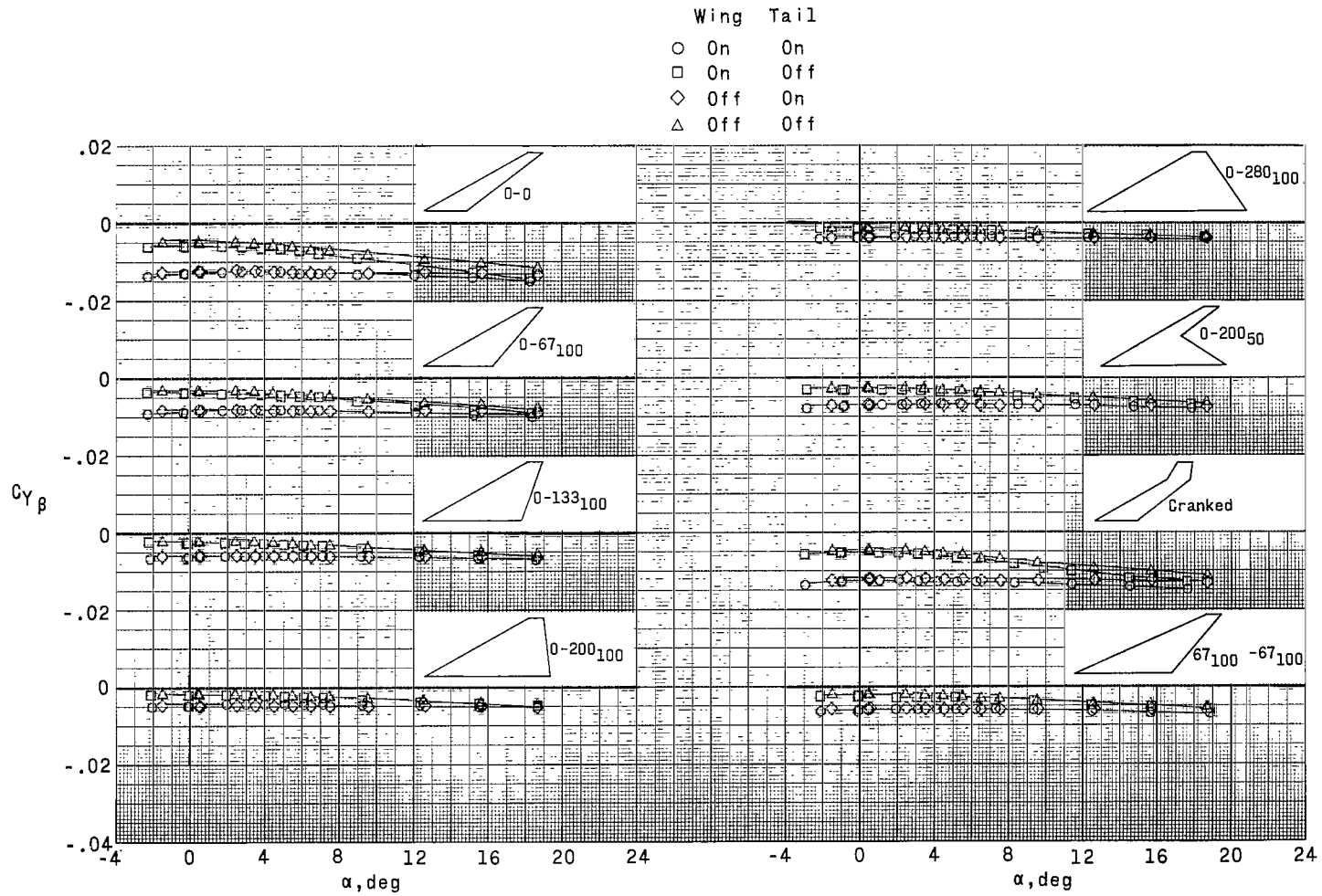
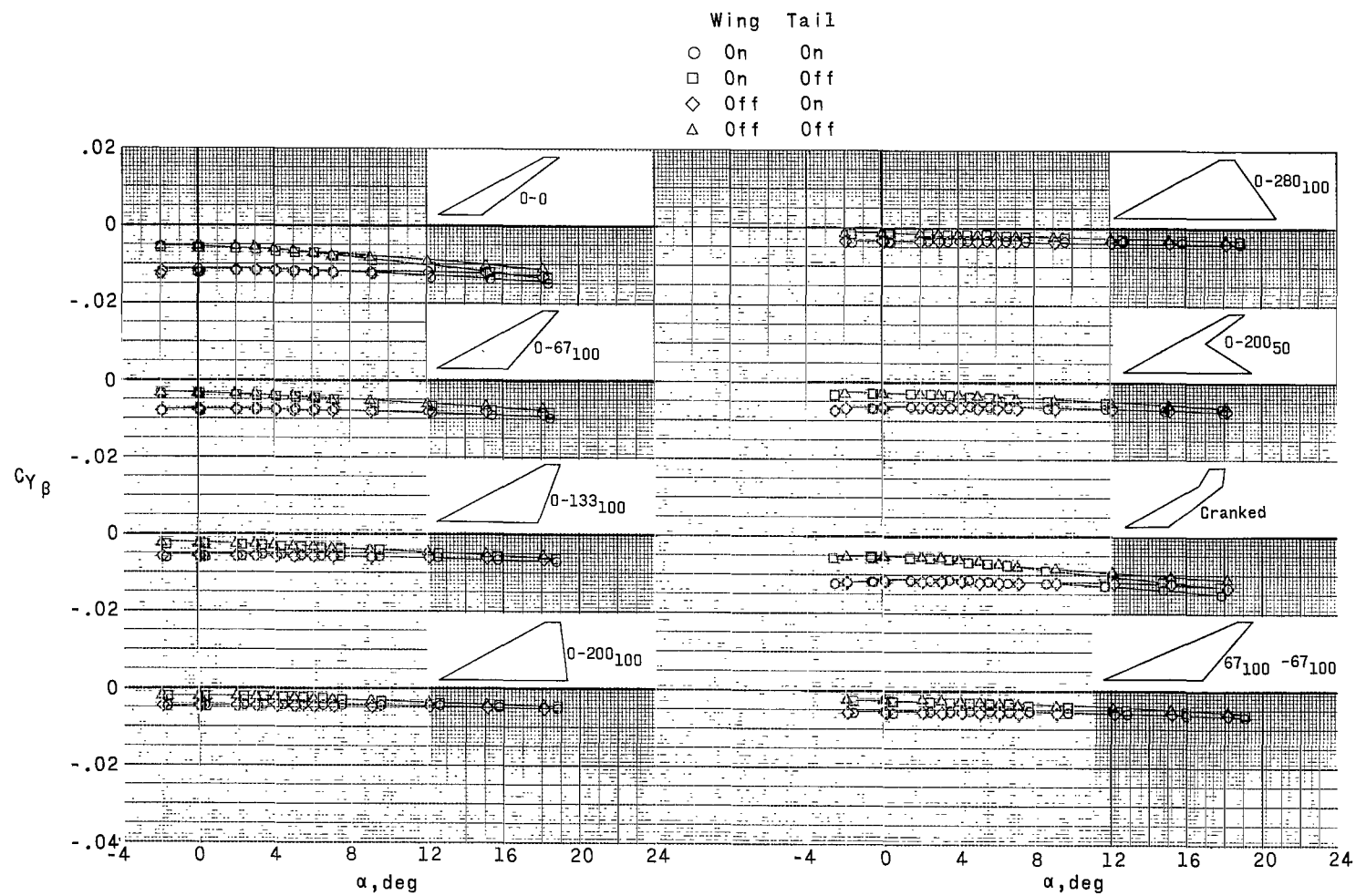


Figure 9.- Continued.



(d) $M = 3.96$.

Figure 9.- Continued.



(e) $M = 4.63$.

Figure 9.- Concluded.

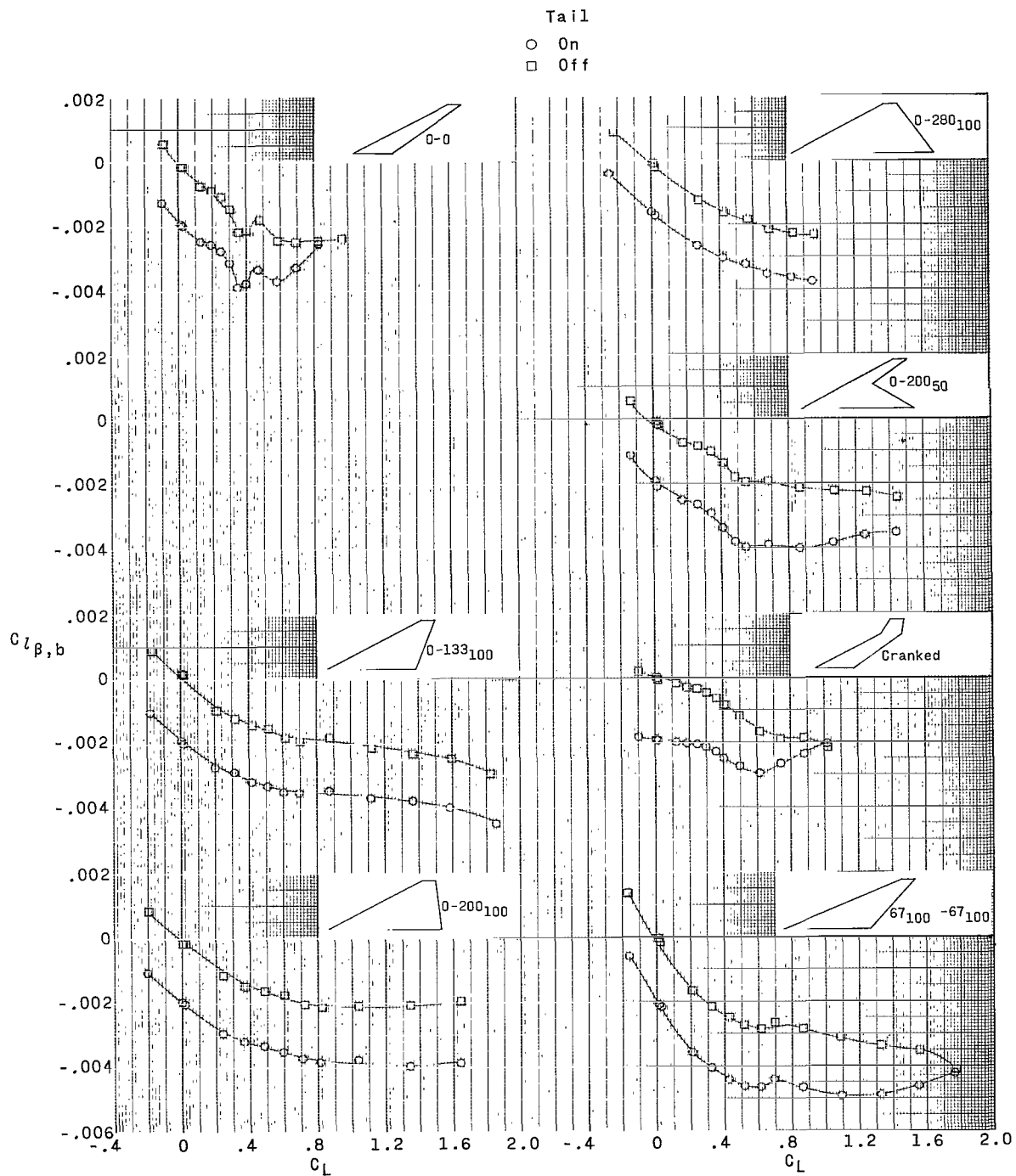
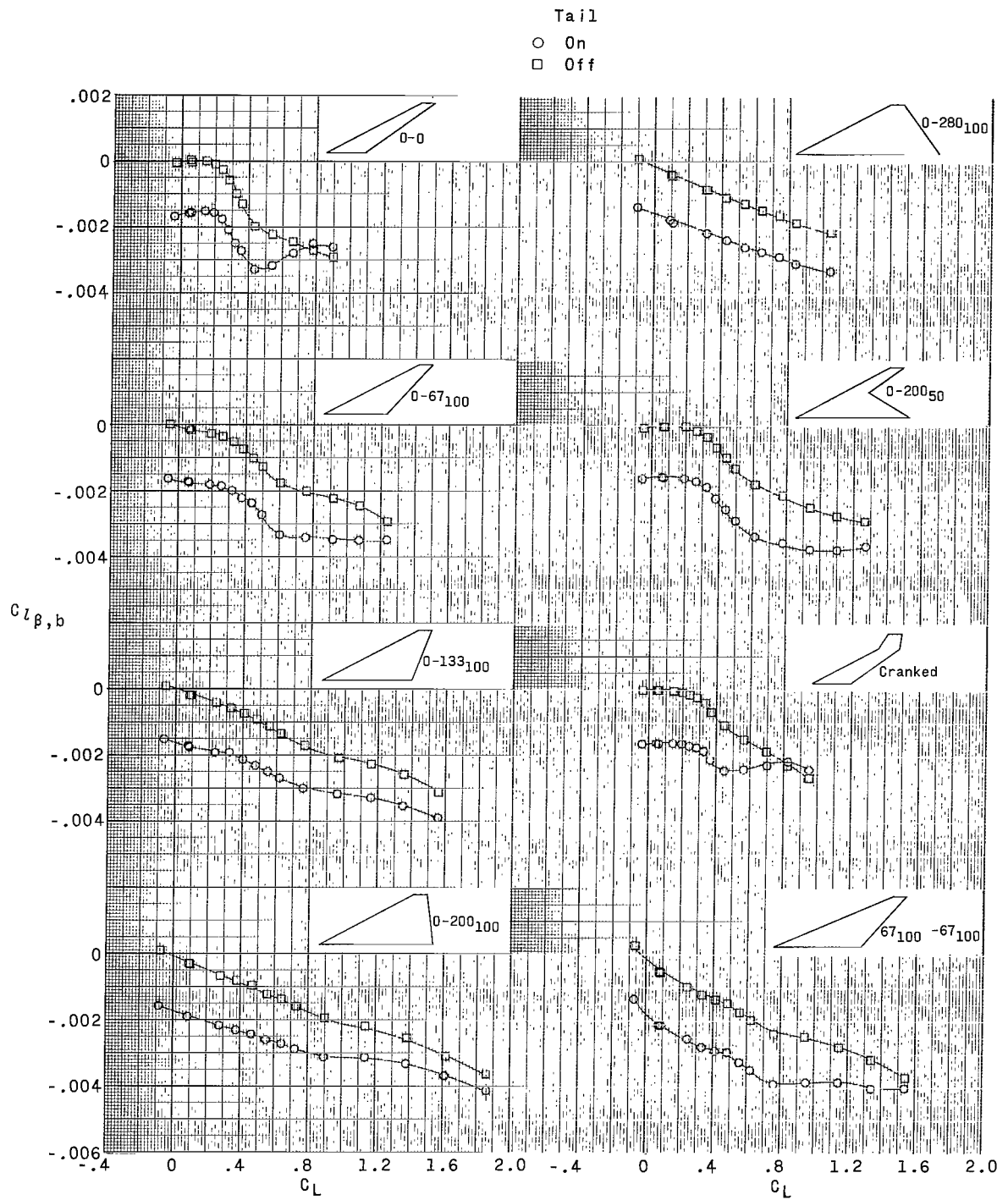
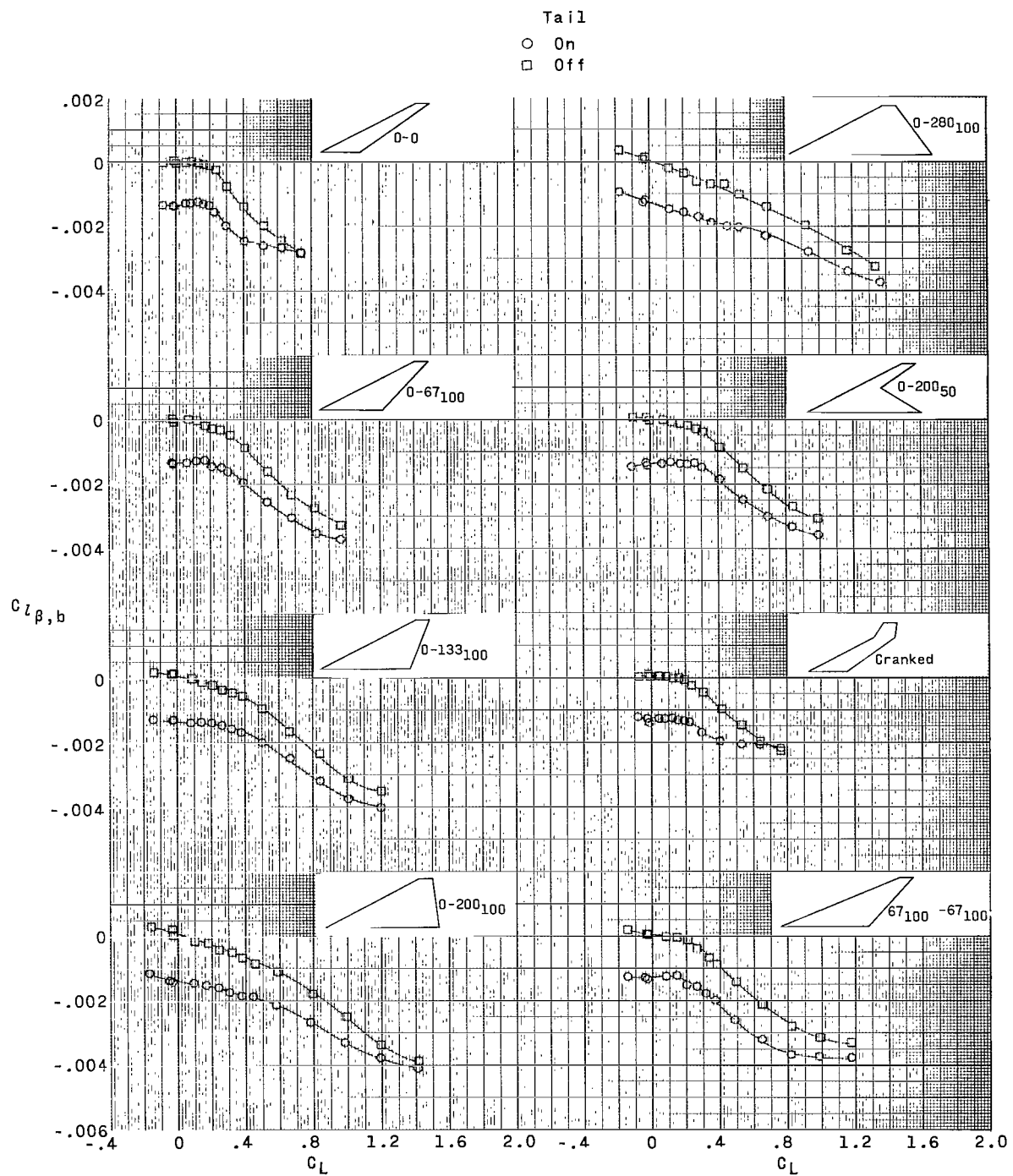


Figure 10.- Variation of $C_{l_{\beta,b}}$ with lift coefficient. Data based on basic wing area and referenced to balance moment center.



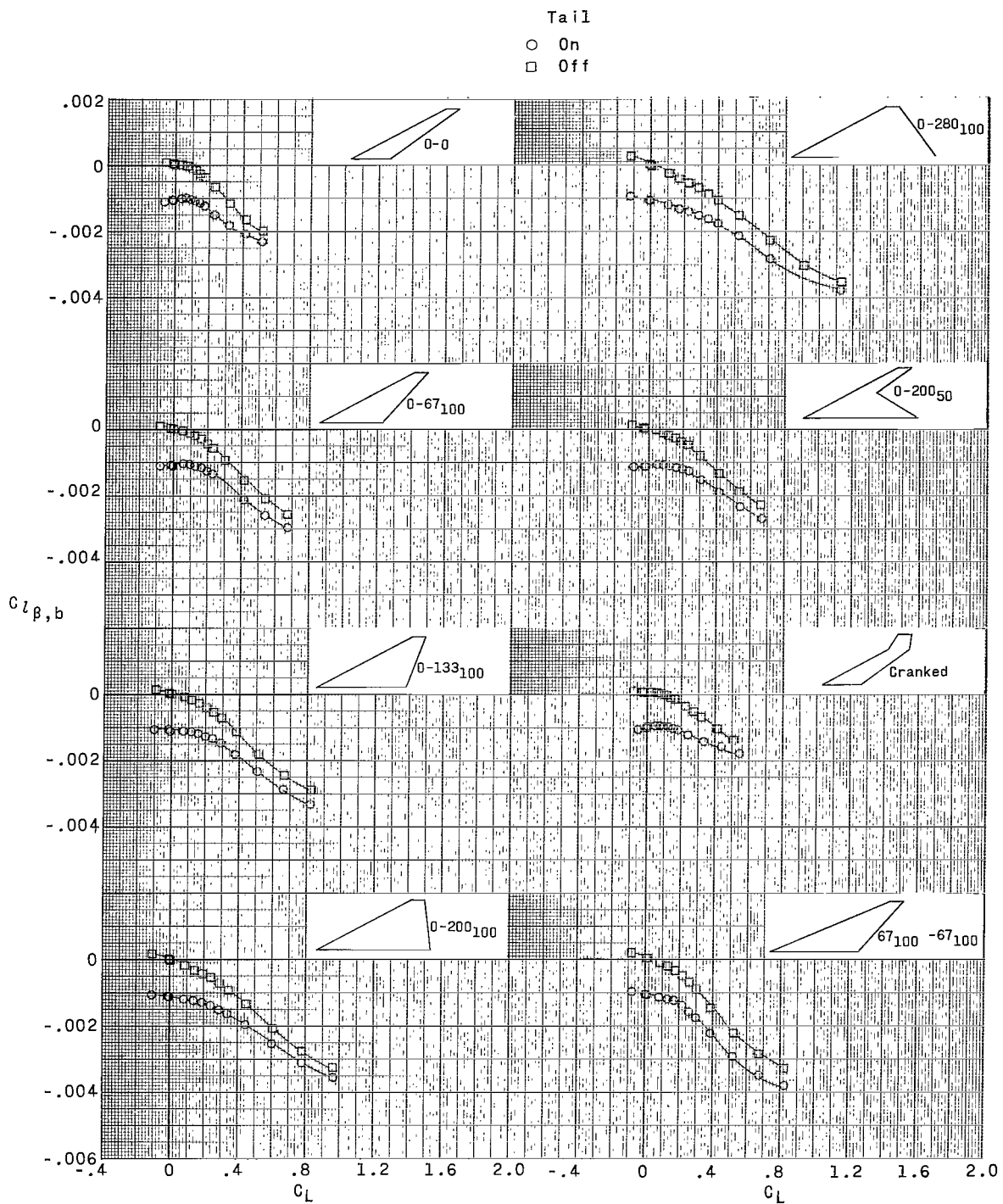
(b) $M = 2.16$.

Figure 10.- Continued.



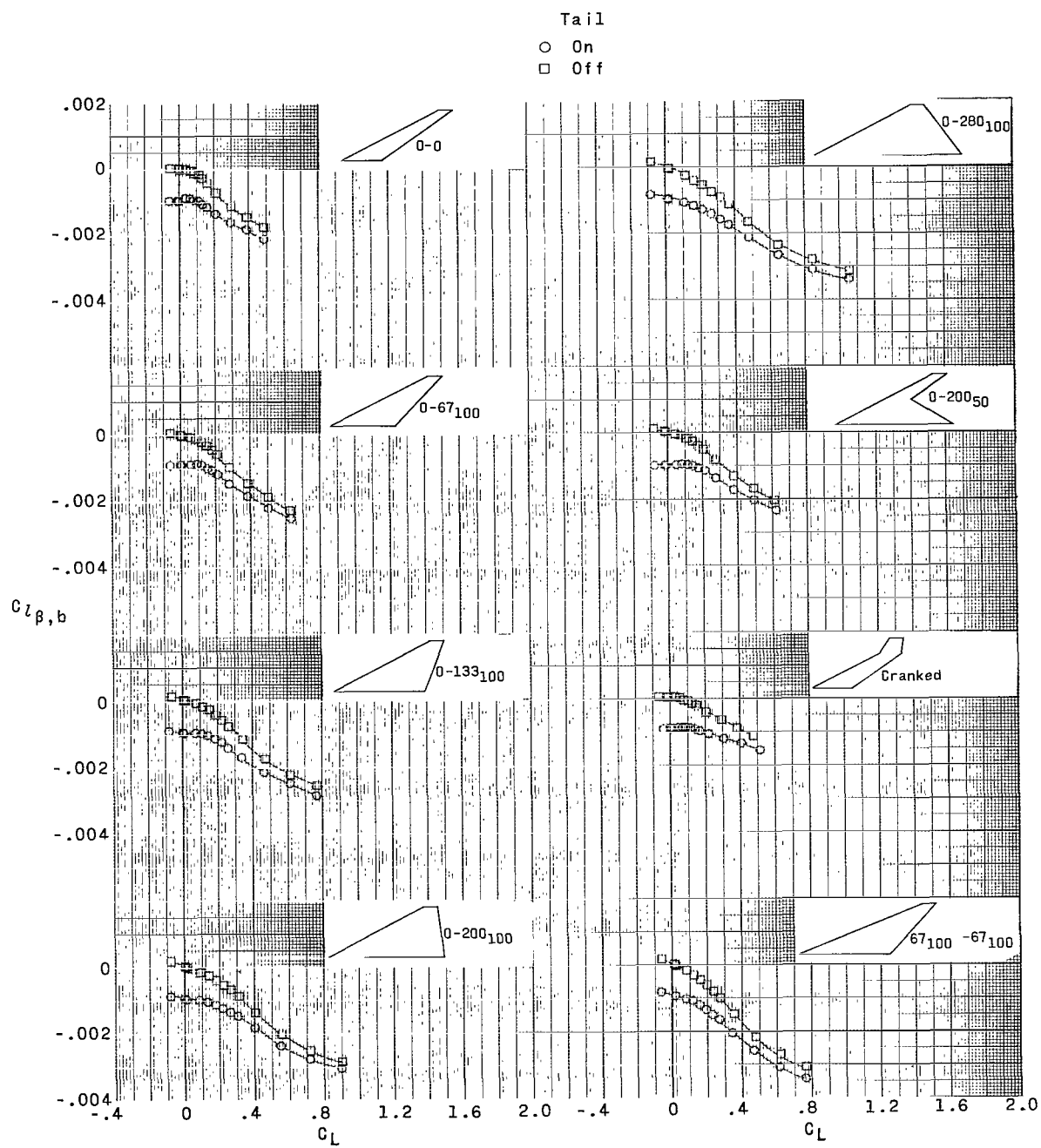
(c) $M = 2.87$.

Figure 10.- Continued.



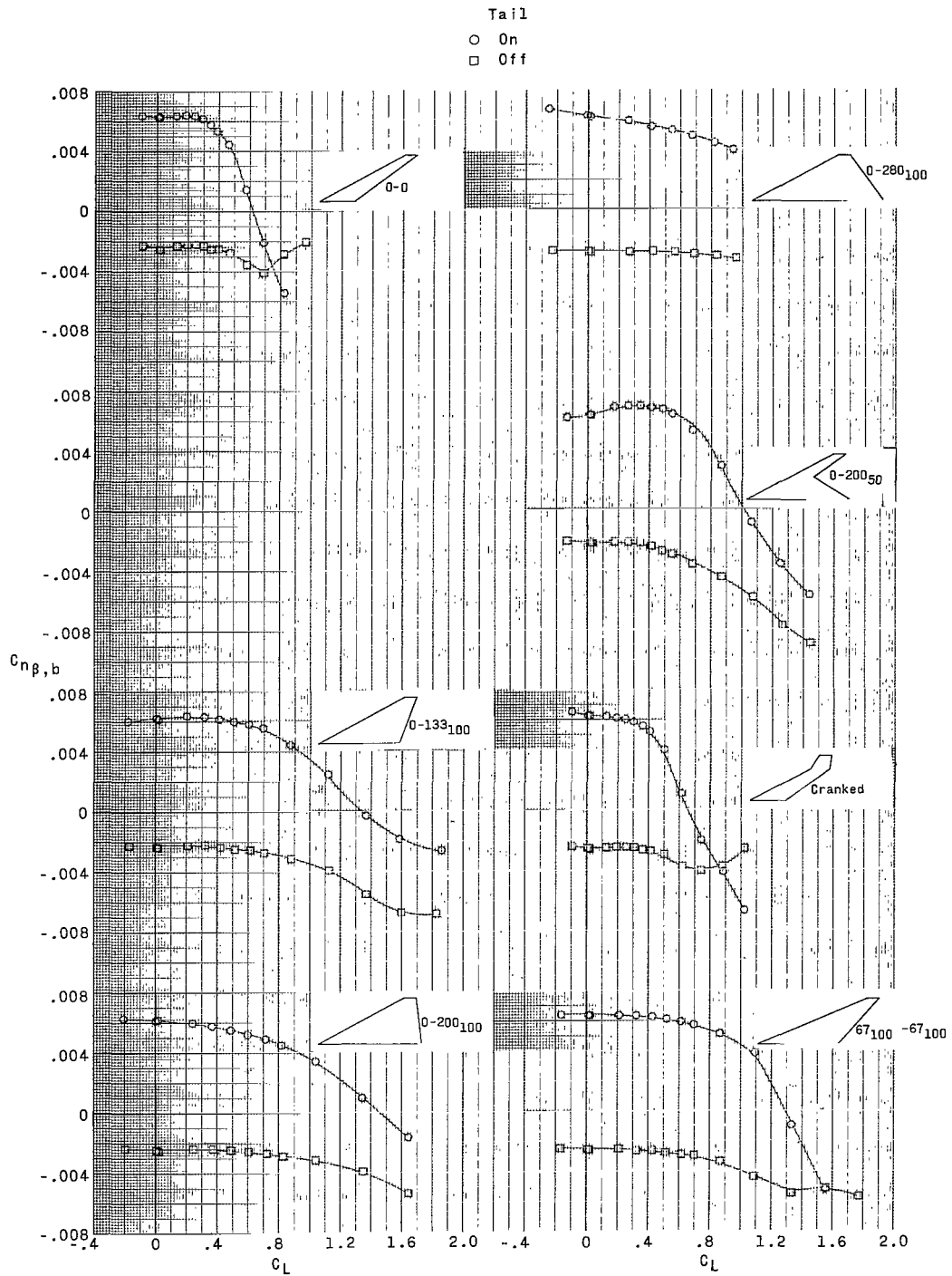
(d) $M = 3.96$.

Figure 10.- Continued.



(e) $M = 4.63$.

Figure 10.- Concluded.



(a) $M = 1.70$.

Figure 11.- Variation of $C_{n\beta,b}$ with lift coefficient. Data based on basic wing area and referenced to balance moment center.

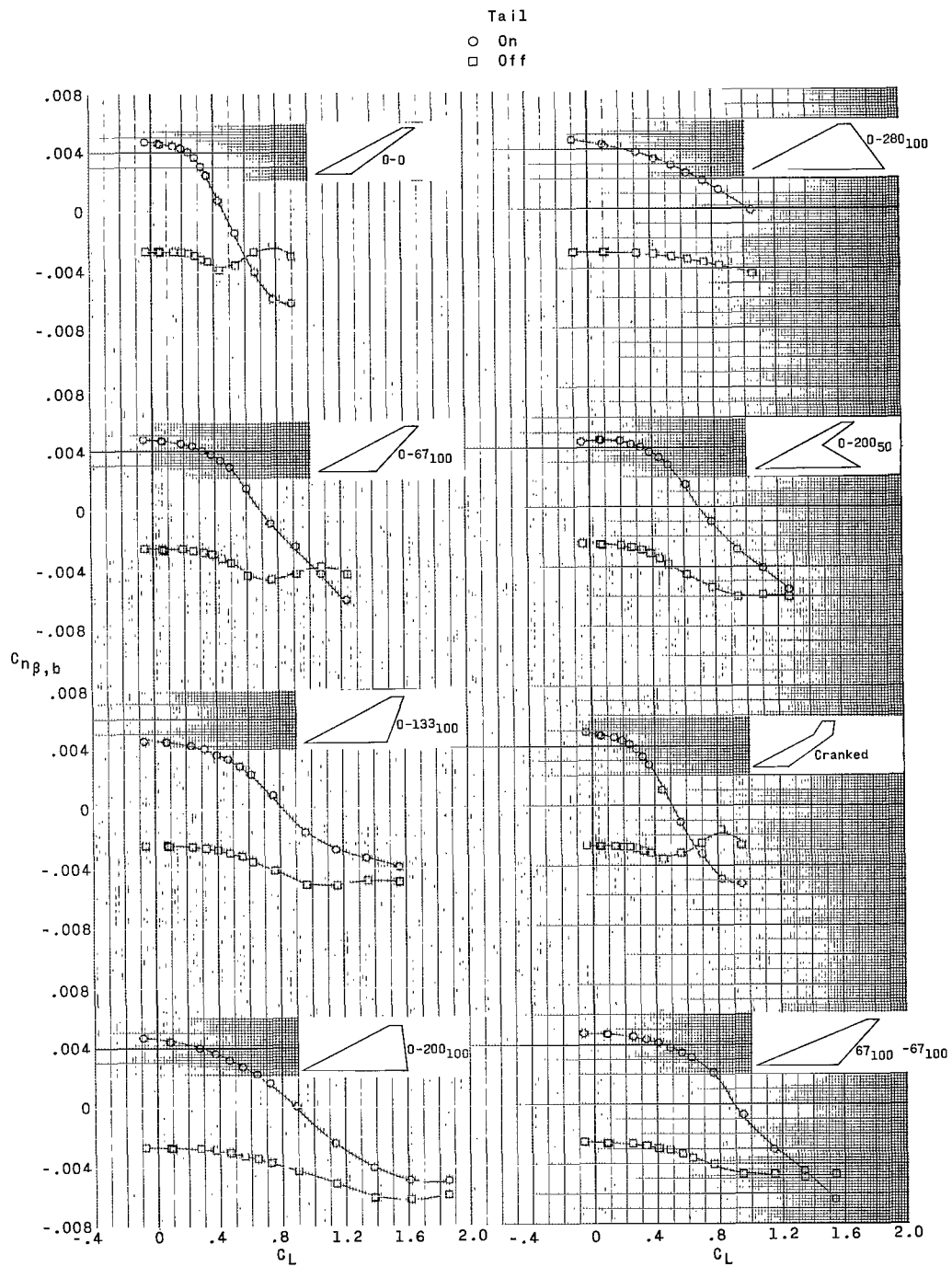
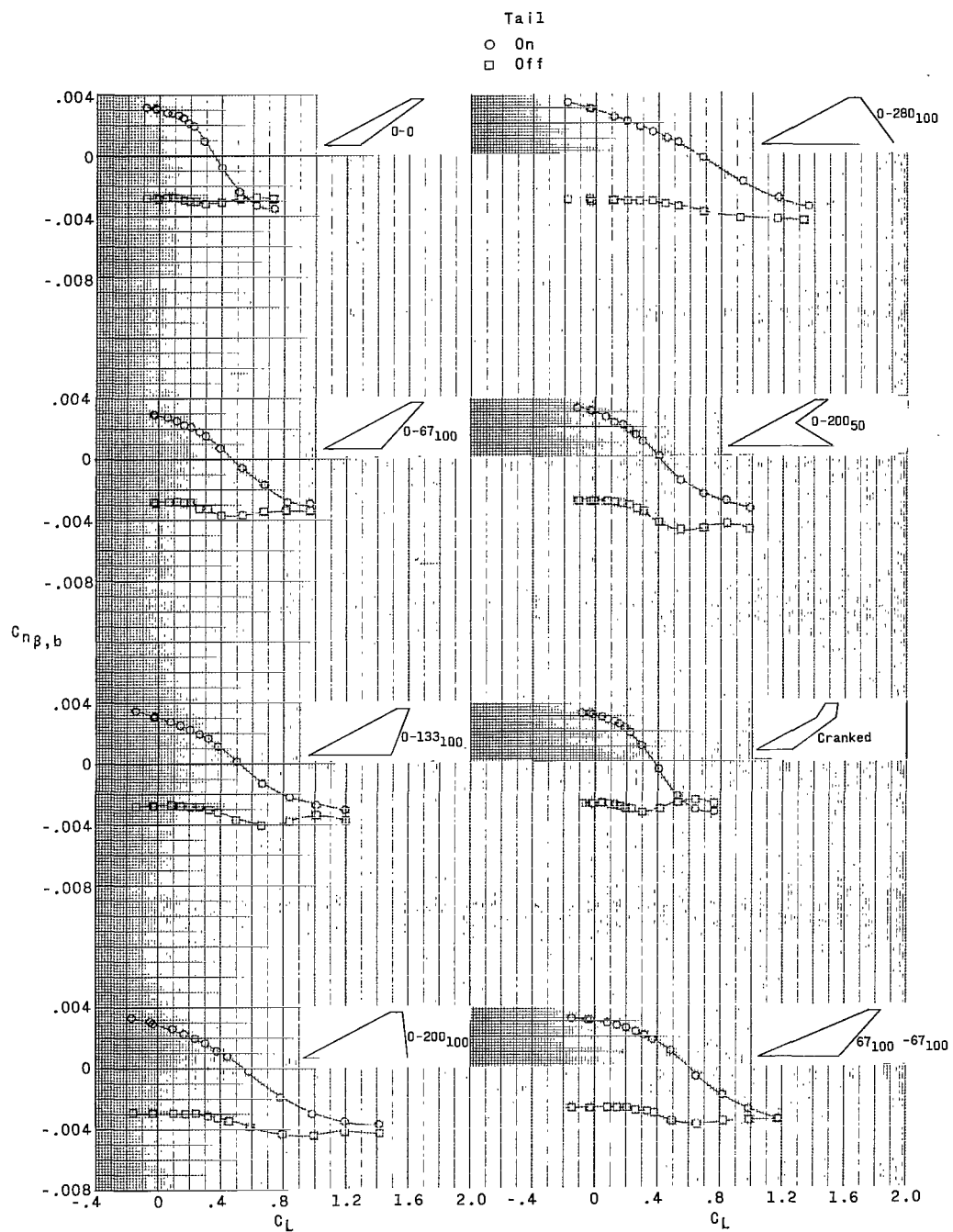
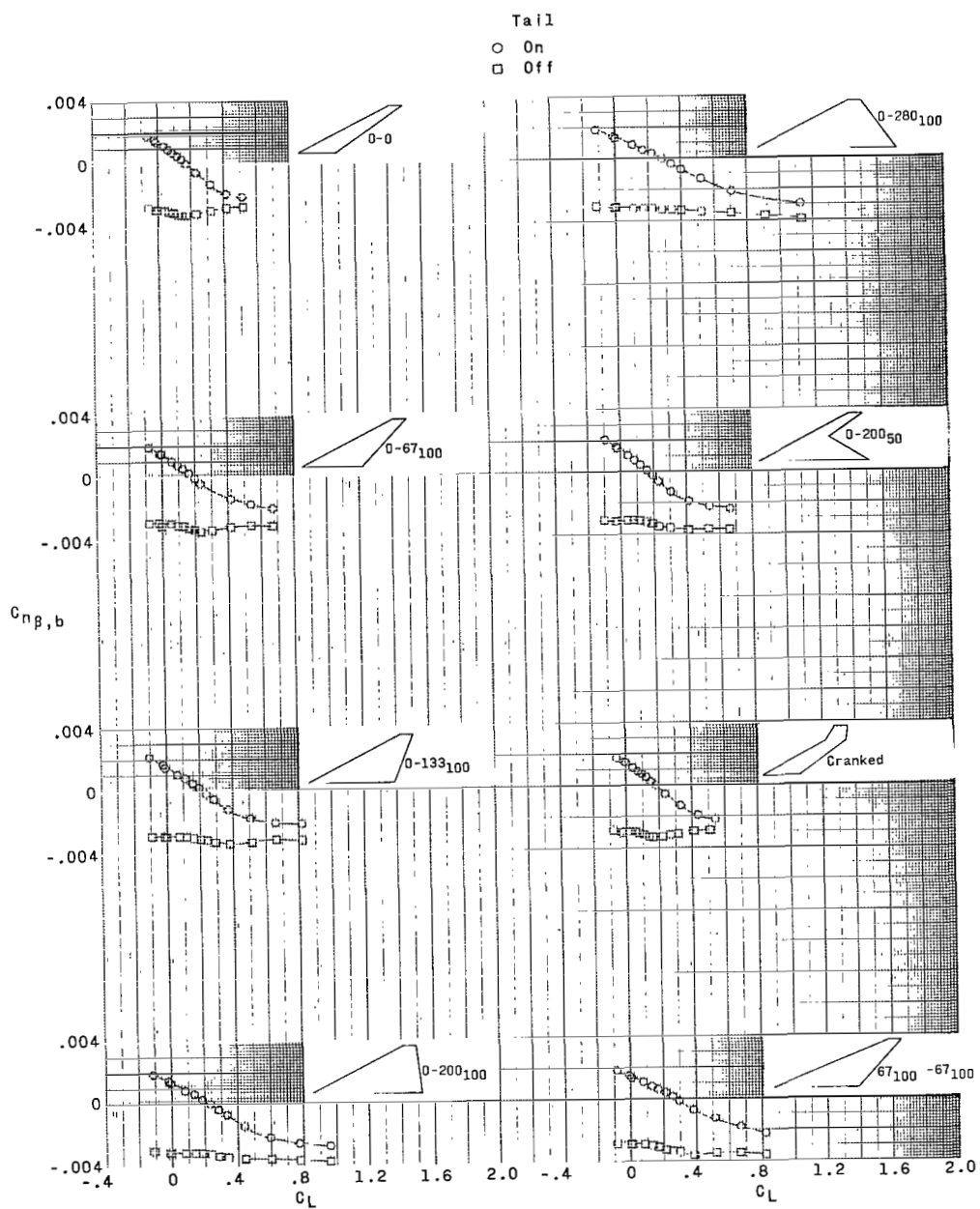


Figure 11.- Continued.



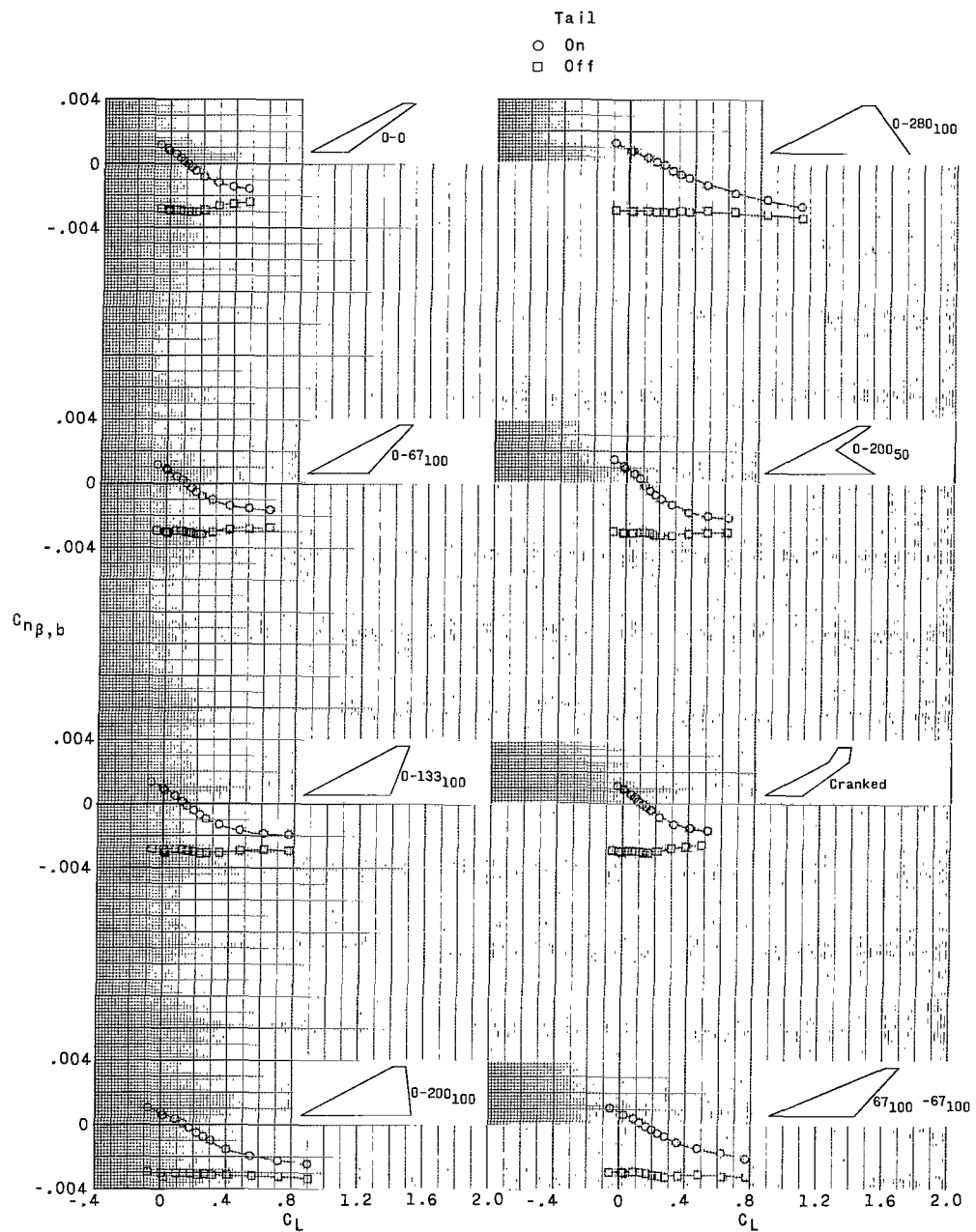
(c) $M = 2.87$.

Figure 11.- Continued.



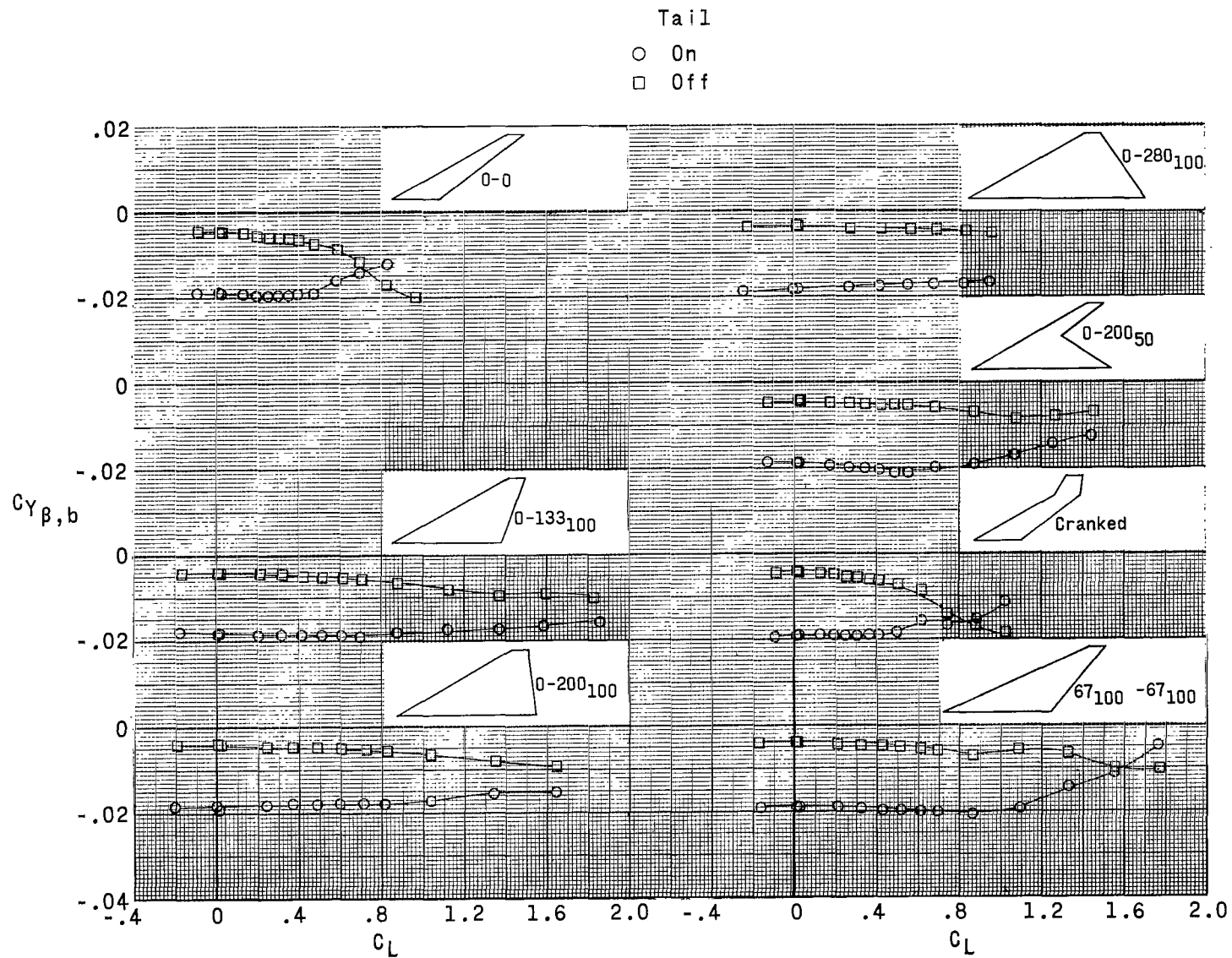
(d) $M = 3.96$.

Figure 11.- Continued.



(e) $M = 4.63$.

Figure 11.- Concluded.



(a) $M = 1.70$.

Figure 12- Variation of $C_{Y_{\beta,b}}$ with lift coefficient. Data based on basic wing area and referenced to balance moment center.

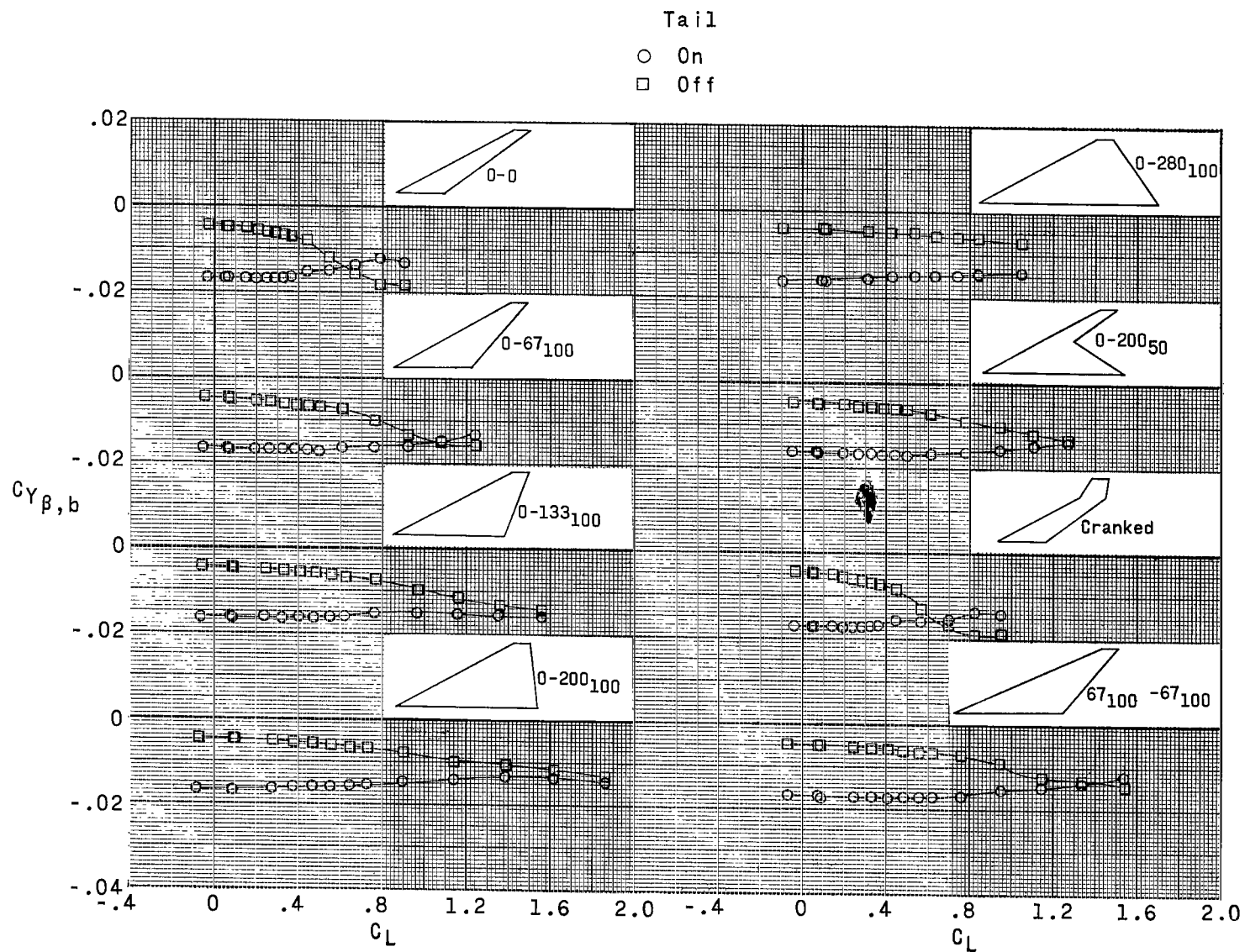
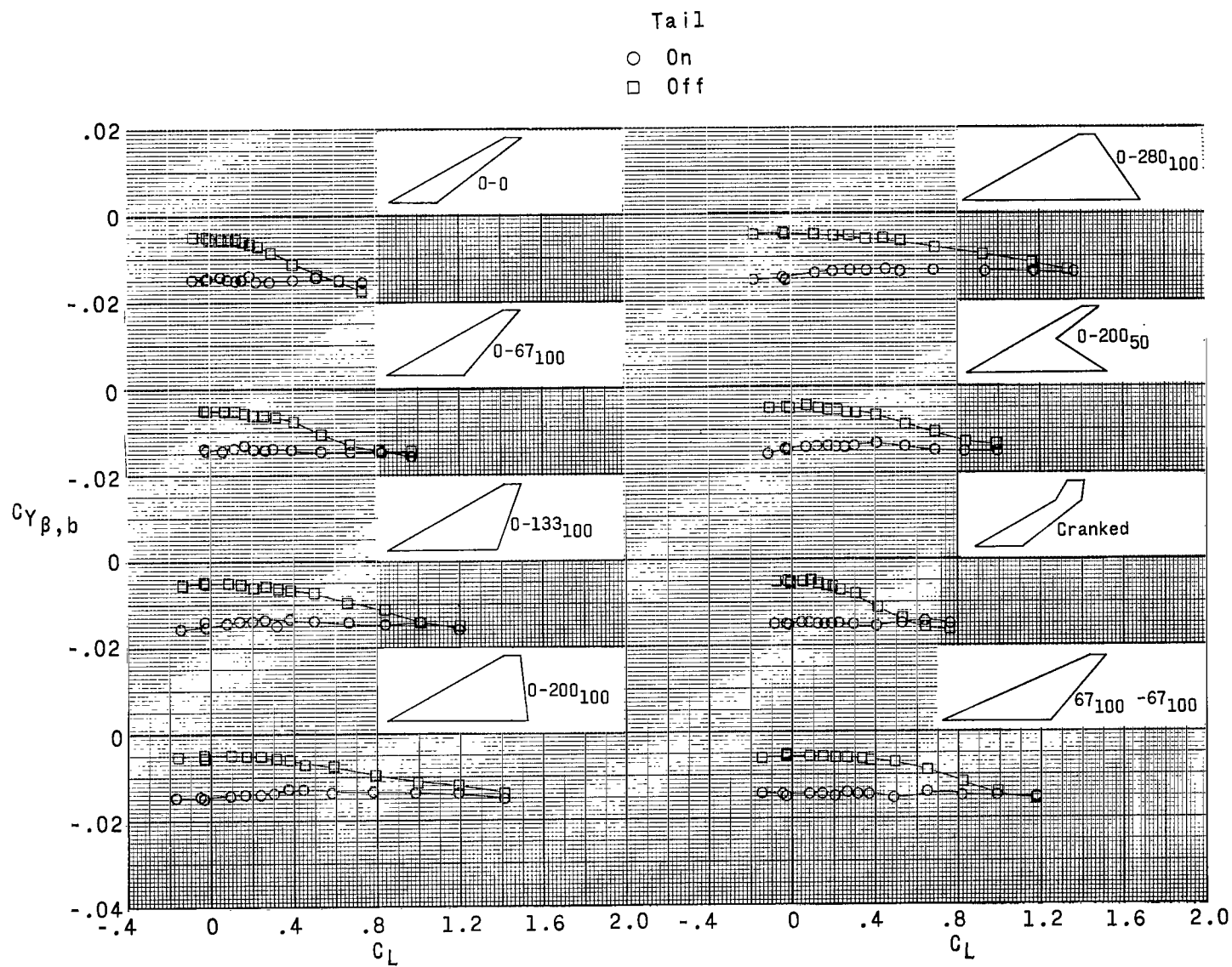
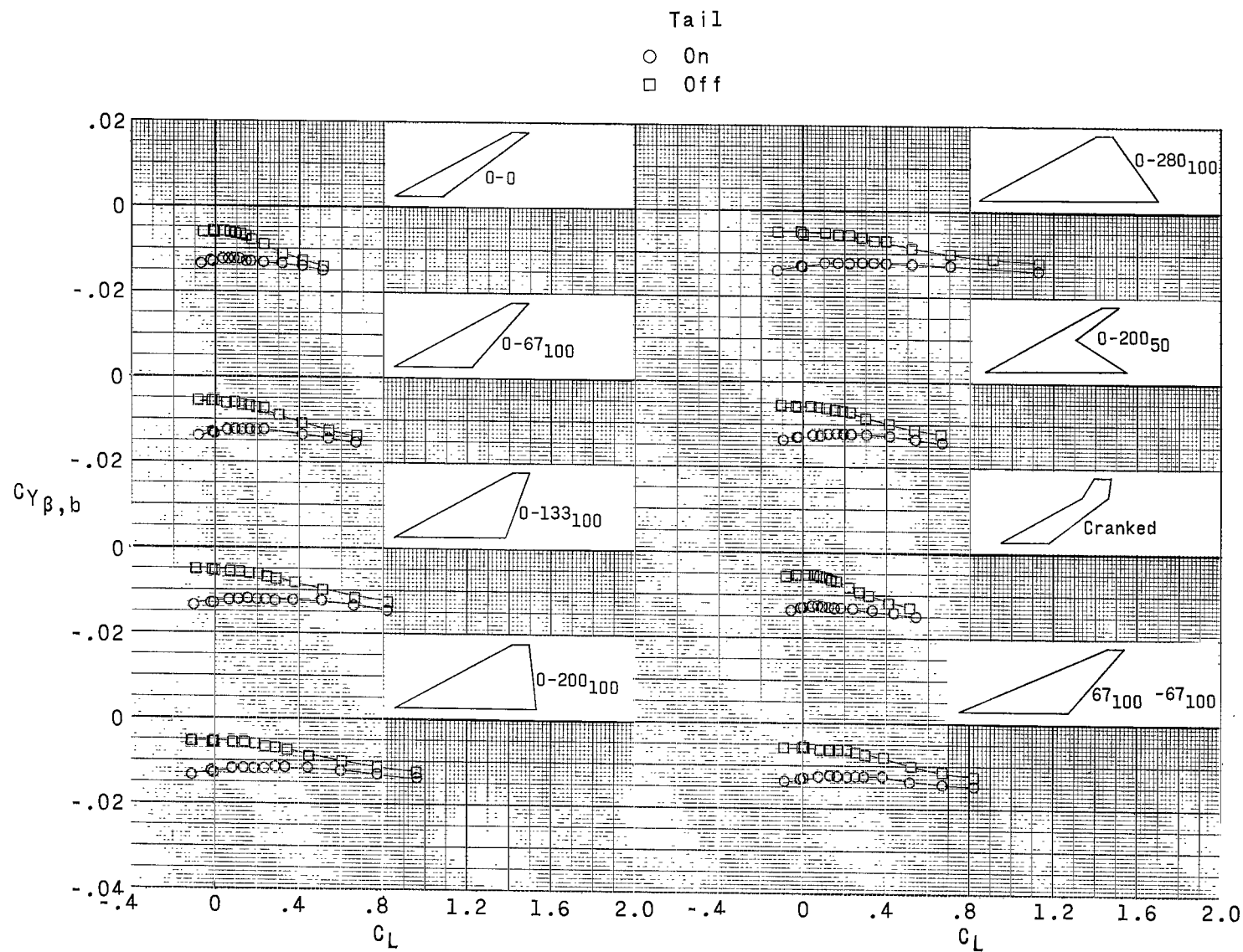
(b) $M = 2.16$.

Figure 12.- Continued.



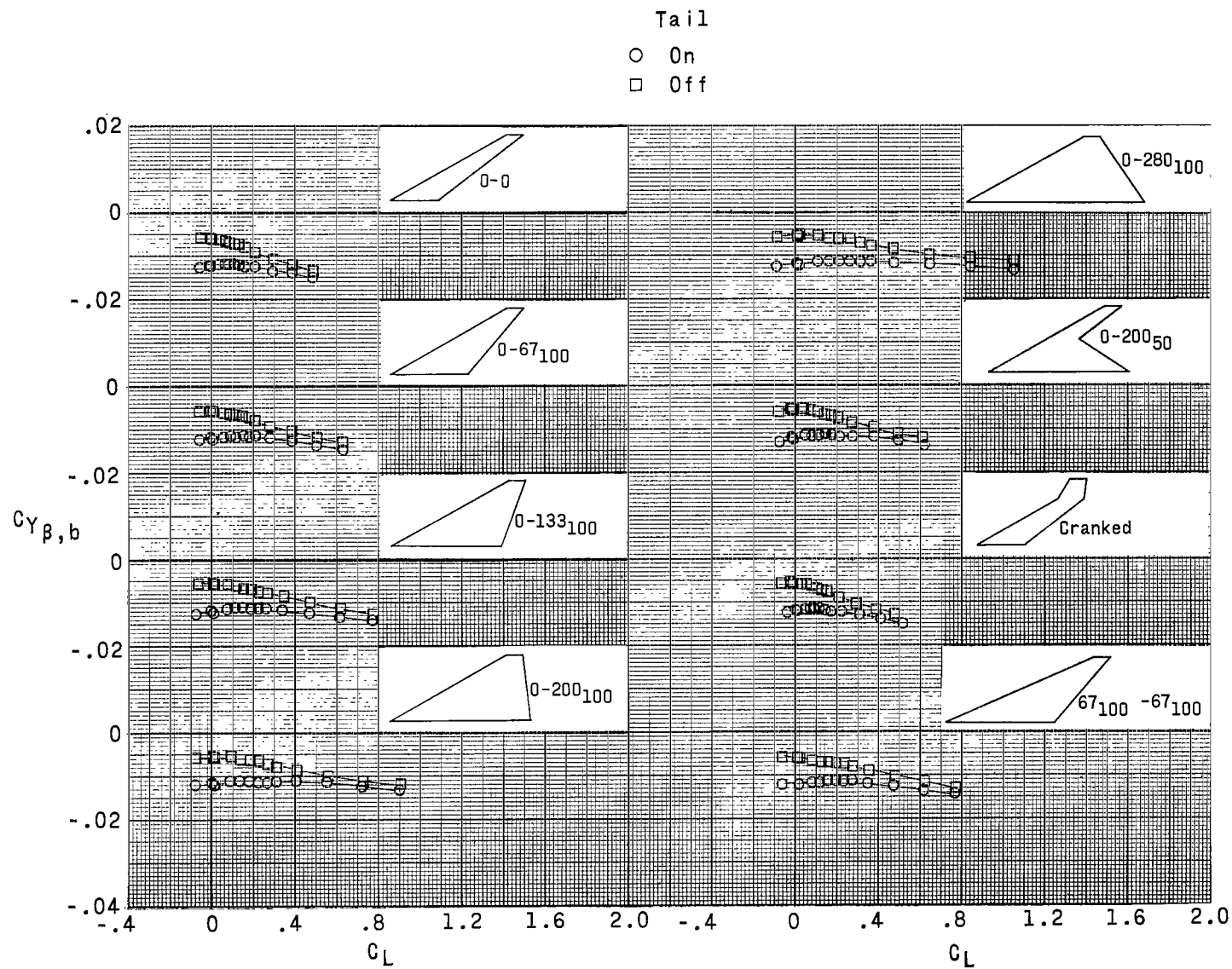
(c) $M = 2.87$.

Figure 12.- Continued.



(d) $M = 3.96$.

Figure 12.- Continued.



(e) $M = 4.63$.

Figure 12.- Concluded.

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"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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